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DEMONSTRATION OF WASTE FLOW REDUCTION FROM HOUSEHOLDS

GENERAL DYNAMICS CORPORATION

PREPARED FOR
NATIONAL ENVIRONMENTAL RESEARCH CENTER

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16. ABSTRACT

A two-year demonstration program was conducted to evaluate water savings, costs, performance and acceptability of various water-saving devices. Reduced flow toilets and flow limiting shower heads were installed in eight single-family dwellings. In three of the homes bath and laundry water was filtered, disinfected, and reused for toilet flushing and/or lawn sprinkling. The experimental portion of the program ran from May 1971 to May 1973.

Water requirements for toilet flushing were substantially reduced in an economically attractive and aesthetically acceptable manner. Shallow trap and dual-flush toilets resulted in average decreases in toilet water usage of 25% and 23%, respectively. Flow restricting shower heads proved to be relatively ineffective, however this result may have been due to use patterns unique to this study.

Wash water recycle systems provided satisfactory operation throughout the test period. The average savings for toilet flushing reuse ranged between 23% and 26% of total water usage. The incorporation of lawn sprinkling as a supplemental reuse mode further reduced waste flow from homes by 16% to 18%. For single-family dwellings, recycle systems could effect marginal cost savings in high water and sewer use rate areas. They are definitely warranted when septic systems with poor drainage (due to soil or topography) are encountered.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Water conservation, *Houses, *Water reclamation, Sewage treatment, Filtration, Disinfection, Cost Analysis	*Sewage flow reduction, *Home water reuse, Plumbing fixtures, Showers, Toilets, Lawn watering	13B

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DEMONSTRATION OF WASTE FLOW REDUCTION FROM HOUSEHOLDS

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CINCINNATI, OHIO 45268

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in:

- o studies on the effects of environmental contaminants on man and the biosphere, and
- o a search for ways to prevent contamination and to recycle valuable resources.

This report covers work on conservation of water in the home. Through the use of reduced flow plumbing fixtures and wastewater recycle systems, it has been demonstrated that significant reductions in water use and sewage flow can be achieved.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

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The performance of this project was carried out under the guidance and supervision of Harold Wallman, Project Manager, and Sheldon Cohen, Project Engineer. The valuable assistance of Donald E. Leone, Senior Biologist/Microbiologist throughout the course of the program is gratefully acknowledged. The assistance of C. Douglas King, Life Sciences, Convair Division of the General Dynamics Corporation, in coordinating activities in the San Diego area is acknowledged with sincere thanks.

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SECTION I

CONCLUSIONS

WATER SAVING TOILET DEVICES

The results of the program show that water requirements for toilet flushing can be substantially reduced by commercially available devices, and in an acceptable manner in terms of functional, economic, and aesthetic considerations. All of the water saving devices tested were convenient to operate, provided satisfactory operation and performance, and scored very well in terms of user acceptance.

Water saving (shallow trap) toilets were found capable of providing reductions in water closet consumption by way of flush volume reductions afforded with the six units tested. The average reduction observed (25%) was somewhat less than anticipated because of the generally lower than average flush volumes of the original conventional toilets. Because of the smaller flush volume utilized by the shallow trap toilet, proper adjustment of the tank level and fill rate was found to be important in achieving satisfactory performance. The unit costs no more than its standard size counterpart, and is definitely warranted for new homes or necessary replacements. However, because of its relatively high initial cost, the shallow trap toilet appears to be of limited economic value for replacement of workable toilets.

Toilet insert devices which converted conventional toilets to dual cycle operation yielded average reductions in toilet flushing requirements of from 18% (Econo-Flush) to 26% (Sink-Bob) by achieving respective flush volume reductions of from 25% to 50% for liquid wastes. The design of the toilet bowl was found to be important in terms of the adequacy of the reduced flush for liquid and/or solid wastes. Hence, although the Sink-Bob device has greater water-saving potential, its effectiveness would be more dependent upon the design of the toilet in which it is installed.

Installation of the toilet inserts in most standard toilets can be readily accomplished by the average homeowner. However, some of the newer toilet models have a rather elaborate flush valve design which would preclude the insertion and use of the devices tested. Due to their low initial cost, as well as their ability to produce significant reductions in water usage, toilet insert devices possess a greater potential for cost savings than any of the other bathroom devices tested. Increased usage and production of the toilet devices should result in even lower initial costs ; additional innovative designs, such as the Saveit toilet insert which was given a preliminary evaluation (when modified for dual flush operation, its flow reducing potential appeared similar to the Econo-Flush), should promote greater acceptance of these devices by the general public.

FLOW LIMITING SHOWER HEADS

The adequacy of a reduced shower flow rate of 13.3 lpm (3.5 gpm) was clearly established in terms of providing an adequate water supply and spray pattern. A further reduction in flow to 9.5 lpm (2.5 gpm) proved unsatisfactory to 33% of the participants.

Despite their low cost, the flow limiting shower heads proved to be of less economic value than anticipated largely because of the rather limited water savings obtained with these devices. This can be traced primarily to the personal bathing habits (lower than average bathing frequency as compared to previous surveys[1] and preference for tub baths as indicated by personal interviews) of the program participants and does not necessarily invalidate their potential. Significant savings in hot water heating costs, in addition to water savings, should also be achieved with flow reducing showers where more frequent shower usage is encountered than in this test program.

WASH WATER REUSE FOR TOILET FLUSHING AND LAWN SPRINKLING

In three of the test homes, the reuse of waste wash water (bath and laundry) for toilet flushing and lawn sprinkling was successfully demonstrated throughout the one-year test period. The recycle system proved to be manageable and simple to use, and capable of reliable and safe operation. No impairment of toilet operation was observed due to the recycling of filtered, disinfected wash water. No significant effects, adverse or beneficial, were noted on lawn growth or appearance throughout the test period or during the next growing season.

In general, the supply of waste bath and laundry water collected sufficed to meet the demands for toilet flushing. The supplemental feedwater requirements averaged only 5% of the total water reused. A 380 liter (100 gallon) storage tank should provide an adequate reservoir for an average size family. The incorporation of lawn sprinkling was found to be useful as a supplemental reuse mode in those homes with an excess of wash water in order to reduce the waste overflow to the waste treatment (septic) system.

The performance attained by the diatomite filter system proved to be satisfactory in terms of aesthetic acceptance by the homeowner and was achieved with relatively low operating costs. Maintenance requirements were found to be similar to those involved in the operation of a small swimming pool. The residual suspended solids in the recycled wash water did produce temporary stains in the toilet bowls which tended to increase cleaning requirements. No problems due to foaming were experienced during refill of the toilet tank.

Continual chlorination of the stored wash water with relatively simple and inexpensive feeders effectively inhibited bacterial growth, and no unpleasant odors were detected during normal operation. Stable chlorine residuals were maintained at the point of reuse despite the presence of interfering agents (soaps, detergents), and any potential health hazard for toilet flushing reuse is considered extremely remote. Reuse for lawn sprinkling may present a possible hazard because of the greater accessibility to the recycled wash water, should any pathogens be present. This potential hazard can be eliminated by suitable underground discharge, but with substantial increased cost.

A comparison of the relative effectiveness of each of the four different kinds of units tested, in terms of water savings, is summarized in Table 1. As anticipated, the wash water recycle system produced the greatest savings in total water consumption. The overall average water savings for toilet flushing and/or lawn sprinkling was 305 lpd, corresponding to a reduction in total water consumption of 26%.

Although the wash water recycle system afforded approximately three to four times as much water savings as was provided by either the shallow trap toilet or dual flush devices (26% vs. 6.9-8.6%), the projected annual cost for a mass produced recycle system of $43/yr is about one to two orders of magnitude greater than the annual cost for the bathroom flow reduction devices. A comparison of the projected recycle system cost of $0.39/1000 liters with the water and sewer use rates in Connecticut indicates that the system can effect marginal cost savings for single homes in high water and sewer use rate areas, and becomes economically attractive only when septic systems with poor drainage are encountered. Cost comparisons with and without septic systems and for ranges of water and sewer charges are shown in Section VIII, Table 29.

Table 1. WATER SAVINGS SUMMARY

Unit tested		No. of units tested	Average no. of occupants	Water savings lpcd[a]	% reduction in total water usage
Wash water recycle system		3	6.3	44.0	26.0
Shallow trap water closet		6	4.5	14.8	6.9
Dual flush device	Sink-Bob	4	2.8	20.5	8.6
	Econo-Flush	4	3.3	12.4	3.3
Flow limiting shower head		11	4.6	2.7	1.0

[a] lpcd = liters per capita-day

The reuse of waste wash water for toilet flushing and/or lawn sprinkling can provide tangible benefits above and beyond the savings in water consumption. The recycle system, by minimizing the surges in outflow to the septic system associated with laundry and bath discharges, as well as by reducing total waste flow, allowed the septic tank and soil absorption system to operate more effectively. In two of the three homes, septic system backup normally experienced was not observed throughout the test period.

SECTION II

RECOMMENDATIONS

1. In order to promote greater public awareness of both the need for and benefits of water conservation, as well as the availability of flow reducing devices for both toilets and showers, broad-based educational/demonstration programs should be considered in selected areas. Such large-scale programs will also generate data with a higher degree of statistical significance than was possible in this program. The water saving customer education and appliance test program recently completed by the Washington Suburban Sanitary Commission[2,3] is an excellent example of the utilization of both software (water saving handbooks) and hardware (toilet inserts, flow limiting shower heads, and inlet pressure reducing valves) in a comprehensive effort aimed at promoting water conservation by the general public. More demonstrations can serve to stimulate further development and mass production of water conservation devices.

In implementing such broad-based programs, a particularly fruitful approach might be to induce participation by the major toilet manufacturers in adaptating one of their standard models for use as a dual cycle toilet. The development of such toilets would preclude any compatibility problems which may exist between certain toilet inserts and some of the current toilet models, provide much greater exposure for this approach to water conservation, and assure professional installation by an experienced plumber.

2. The extension of the wash water reuse concept to multiple family dwellings should be investigated in order to determine its potential attractiveness for water conservation and waste flow reduction. Reuse on a multiple-dwelling basis should be more economical than for a single dwelling. Scale-up of the system developed for single family dwellings should not only permit substantial reductions in both initial and operating costs, on a per capita basis, but also allow significant improvements in recycle system design and performance with minimal impact on total system costs. The need for installation of a separate

distribution system for toilet flushing should not alter the economics in a decisive manner. All of the foregoing presumptions need to be assessed in the light of further detailed design and cost analyses. In addition, public attitudes toward the reuse of waste wash water on a communal basis will have to be further explored. Public safety in regard to the possible transmission of pathogenic organisms must also be carefully considered. It is therefore recommended that a preliminary study phase be conducted, prior to the design and construction of a prototype unit, in order to ascertain economic feasibility, public acceptance, and any potential health hazards.

3. The results of this project show that reuse of waste wash water at the single household level for toilet flushing and lawn sprinkling can be applied successfully. Also, the projected economics look marginally favorable for high user charge areas and where septic systems are flow limited. Further work on fixing the cost of a mass produced reuse system for single family dwellings could make the economics more favorable. It is therefore recommended that a larger-scale demonstration program be considered, for single family dwellings, which would incorporate as an initial phase the development and detailed costing of a prototype unit suitable for mass production. Such a program would (a) result in a cost and performance optimized system, (b) clearly establish the acceptability and safety of this approach to the homeowner, and (c) could lead to the availability of a marketable unit.

4. The previous recommendations regarding home water conservation are justifiable on the basis of cost savings to the individual homeowner. On the larger scale of net cost savings to the community, however, there may be more effective ways of conserving water and reducing waste flow. Technological concepts related to wide scale reuse, reduction of infiltration and integration of utilities could be more important than home water saving. User attitudes and rate structures could also have a determining influence. It is therefore recommended that a broad study be made of the technological, economic, public health, aesthetic and sociological factors relative to water conservation and waste flow reduction, in order to determine where the most incentive exists for further research, development and demonstration.

SECTION III

INTRODUCTION

BACKGROUND

The austere reality of a fixed natural fresh water supply combined with a continuously expanding demand has promoted an increasing awareness of the need for developing new long-term approaches to water management. In recent years, this need has become more acute as the country becomes increasingly involved with controlling water pollution. According to the Office of Saline Water,[4] our water needs are expected to double by 1980 (from 1.5 to 3 billion cu m/day or 400 to 800 billion gal/day), and by the year 2000, total water consumption for the United States may be as much as 4 to 8 billion cu m/day.

In a previous engineering study performed by General Dynamics for the Federal Water Pollution Control Administration,[1] it was concluded that reduction of water usage appeared to be the most practical and economically feasible approach to both water conservation and waste treatment at the household level, and would not become obsolete as new treatment technology is developed. The study cited many household functions in which water is being used wastefully. In particular, the study indicated that water for toilet flushing and bathing could be reduced by approximately 35% by using presently available devices and technology.

The practice of water reuse at the household level is another possible means of reducing both water usage and waste treatment requirements. In particular, the use of waste wash water for toilet flushing (or lawn sprinkling) appears to be the simplest and most practical method of conserving water through reuse. In a city of 100,000 these savings could amount to more than eight thousand cubic meters of water per day that would not have to be supplied to the user and eventually treated in the waste treatment plant. Besides savings in operating costs for water supply and waste treatment, the decreased usage would delay the need for construction of new waste treatment facilities, for construction of larger sewer lines and water mains, and for the development of new water sources which are becoming increasingly scarce and costly.

PROGRAM OBJECTIVES AND SCOPE OF WORK

The main thrust of this program was to evaluate the relative merits, water savings, costs, acceptability, and potential attractiveness of (a) various presently available bathroom flow reduction devices, and (b) schemes for the reuse of household wash water for toilet flushing and/or lawn sprinkling. The flow reduction devices and recycle systems were installed on a voluntary basis in a representative group of eight homes to reduce water consumption in three major water use areas: (1) toilet flushing, (2) bathing, and (3) lawn watering. In five of the homes, shallow trap water closets and/or dual-flush devices were used to reduce the water requirements for toilet flushing, and flow limiting shower heads were used to reduce bathing water consumption (see Figure 1). In the three remaining homes, in addition to the flow reducing devices, an alternate approach was implemented in which waste laundry and bath water were filtered, disinfected, and pressurized for reuse in toilet flushing and/or lawn watering (see Figure 2).

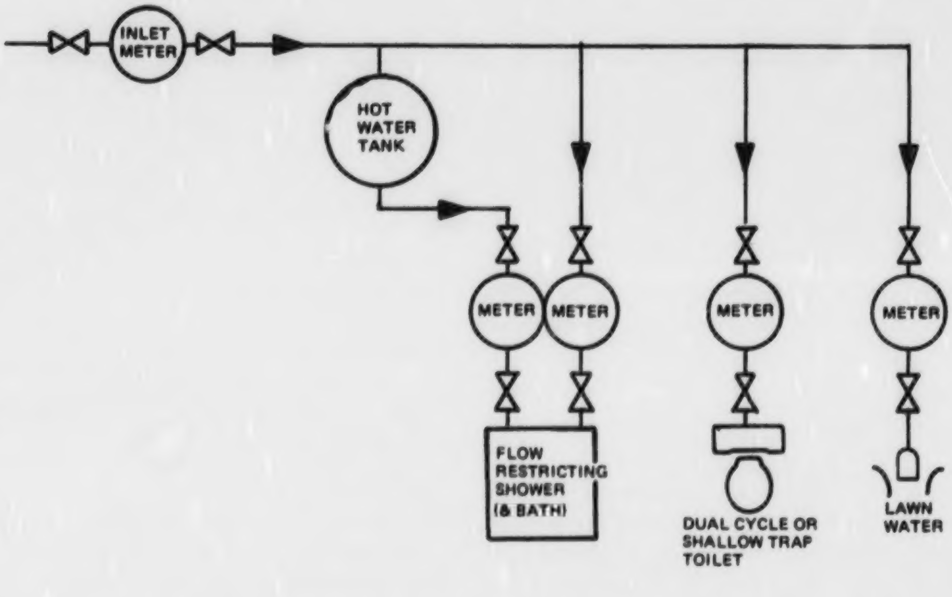
INLET METER
HOT WATER TANK
METER
METER
METER
METER
FLOW RESTRICTING SHOWER (& BATH)
DUAL CYCLE OR SHALLOW TRAP TOILET
LAWN WATER

Figure 1. Schematic diagram for homes with flow restricting shower and dual cycle or shallow trap toilet

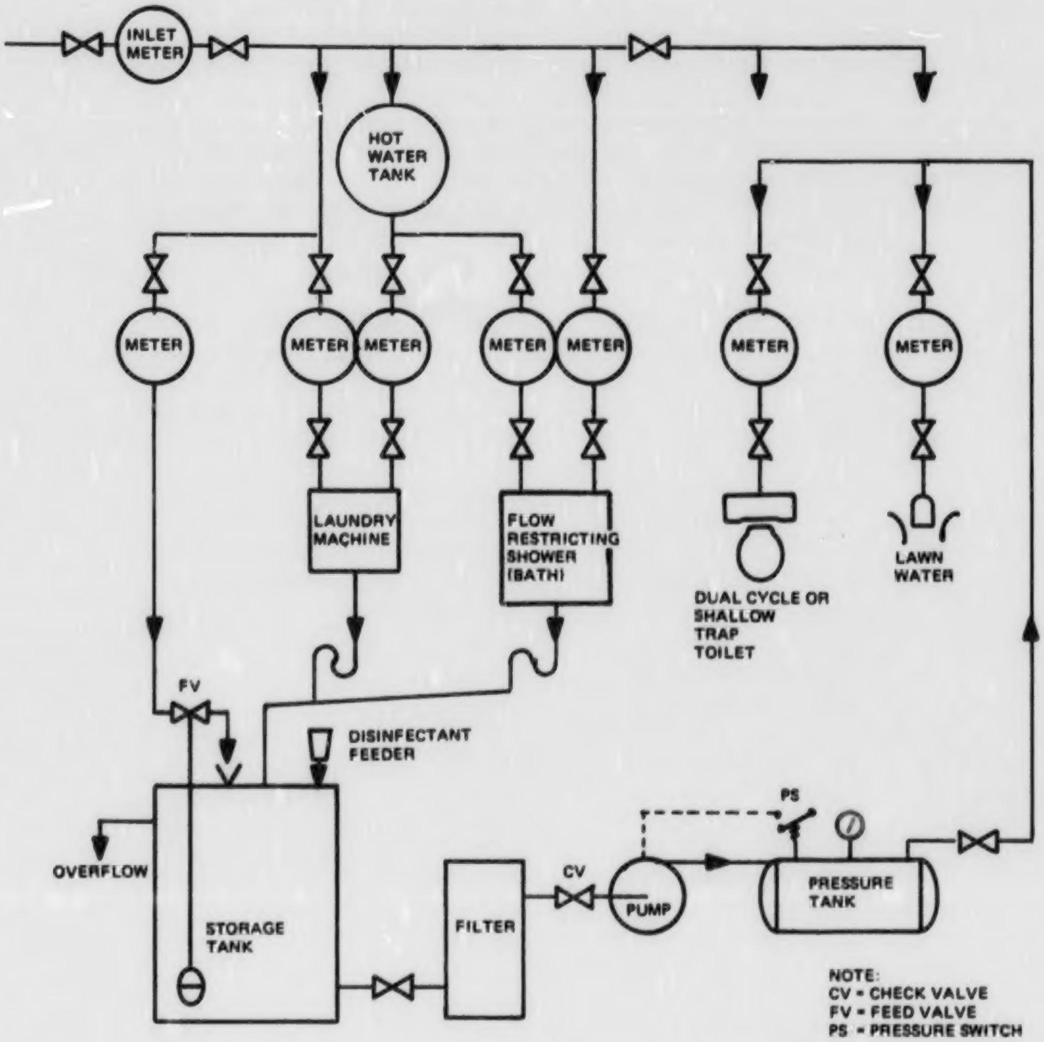
INLET METER
HOT WATER TANK
METER
LAUNDRY MACHINE
FLOW RESTRICTING SHOWER (BATH)
DUAL CYCLE OR SHALLOW TRAP TOILET
LAWN WATER
FV
DISINFECTANT FEEDER
OVERFLOW
STORAGE TANK
FILTER
CV
PUMP
PS
PRESSURE TANK
NOTE:
CV = CHECK VALVE
FV = FEED VALVE
PS = PRESSURE SWITCH

Figure 2. Schematic diagram for homes with flow restricting shower, dual cycle or shallow trap toilet, and wash water recycle system

The work performed in this program was accomplished in three major phases as outlined below:

1. Meters were installed in the eight test homes to determine normal water use patterns for a period of six months. During this period, the design, selection and procurement of all necessary devices and systems were accomplished.

2. The bathroom flow reduction devices and recycle systems were then installed in the eight test homes for a period of one year. Throughout this period, both water consumption and performance of all devices and systems were continually monitored.

3. The water saving devices and systems were then removed, and the monitoring of normal water usage was continued for an additional six months to minimize any bias in the results due to seasonal changes or long-term variations in family habits.

In addition to the analysis and evaluation of all data collected during the program, all systems and devices tested were evaluated in terms of homeowner acceptability through the use of informal interviews and formal questionnaries completed by all adult occupants.

SECTION IV

NORMAL WATER USE PATTERNS

HOMEOWNER SELECTION

The homes of eight volunteer families were chosen for the test program. To facilitate installation, inspection, and data collection, six of the homes were chosen in the vicinity of the Electric Boat Division facilities (four in southeastern Connecticut and two in adjacent Rhode Island). Two additional homes were chosen in a water-short region (San Diego, California). The homes and families were carefully chosen to obtain representative conditions of water use and typical installation costs. Additional guidelines for selection of the demonstration homes included homeowner interest and cooperation, single family dwelling with 3 or more occupants, accessible plumbing for meter installation, and drain lines suitably located for installation of recycle systems.

Various relevant characteristics of each of the test homes and families are shown in Table 2. The number of occupants (adults and children) listed in the table reflect conditions at the start of the two-year test program. Due to fluctuations in the number of occupants for some of the families throughout the program, the final average number may not be the same as that shown in the table. Toilet characteristics are also included to serve as a basis for correlation of the water use data obtained during both control and test periods. Table 3 indicates both the number and specific distribution of each of the household flow reduction devices and systems installed in each test home.

HOUSEHOLD WATER CONSUMPTION DURING CONTROL PERIODS (PHASES I AND III)

Throughout most of the two-year test program (May 1971 - May 1973), water usage was recorded by each of the eight homeowners, on a weekly basis, on data forms similar to that shown in Figure 3. In all eight homes, toilet, bath/

shower and inlet (total) usage were monitored. In five of the homes, laundry usage was also monitored, and the two homes in San Diego (#1 and #2) recorded lawn water consumption.

Table 2. TEST HOME CHARACTERISTICS

Single family homes	Water supply	Service water pressure cm Hg	Waste disposal	Adults[a]	Children[b]	Number of baths	Toilet design	Flush Vol., liters
#1	City (metered)	284	Sewers	1-W 1-NW	1-S 2-PS	1	Reverse trap	17.2
#2	City (metered)	320	Sewers	1-W 1-NW		3	Siphon jet	14.3/ 16.3/ 16.7
#3	Individual well	104-208	Septic tank	1-W 1-NW	1-S 1-PS	1	Reverse trap	12.5
#4	City (metered)	232	Sewers	2-W	2-S	1	Siphon jet	16.3-20.8
#5	City (metered)	475	Sewers	1-W 1-NW	1-S	1	Siphon jet	14.4
#6	City (metered)	300	Septic tank	1-W 1-NW	7-S 1-PS	1	Siphon jet	17.9
#7	Regional (metered)	388	Septic tank	1-W 1-NW	3-S.	2	Reverse trap	13.6/ 17.0
#8	Regional (non-metered)	284	Septic tank	1-W 1-PT	3-S	1½	Wash-down	15.5/ 15.5

[a] W=Working
NW=Non-working

PT=Part time

[b] S=School
PS=Pre-school

Table 3. DISTRIBUTION OF HOUSEHOLD FLOW REDUCTION DEVICES

Single family homes	Shallow trap toilets	Econo-Flush	Sink-Bob	Shower heads 9.5 lpm	Shower heads 13.3 lpm	Toilet flushing	Lawn sprinkling
#1	1	--	--	--	1	--	--
#2	1	2	2	--	3	--	--
#3	1	--	--	1	--	--	--
#4	1	--	--	1	--	--	--
#5	1	--	--	--	1	--	--
#6	1	--	--	1	--	1	1
#7	--	2	--	--	2	1	1
#8	--	--	2	--	1	1	--

HOME NO.____/PHASE____

DATE									
TIME									
METER READINGS, GALLONS	WATER CLOSET								
	BATH	COLD							
		HOT							
	LAUNDRY	COLD							
		HOT							
	INLET								
NUMBER OF OCCUPANTS									
UNUSUAL CONDITIONS									

COMMENTS:

Figure 3. Typical data collection form

The control period, during which normal water use patterns were monitored, was broken down into two six-month periods (Phases I and III) covering the beginning and end of the two-year test program. Water consumption data for the control period are summarized in Tables 4, 5, and 6. Average values for each household as well as overall averages for the entire group are shown for each function monitored. The data are best presented on a per capita basis due to changes in the number of occupants in all but two of the test homes. Atypical data resulting from leaks, unusual circumstances, etc., were not included in the data summaries.

Table 4. PHASE I - WATER CONSUMPTION DATA
(5/71 - 11/71)

Home- owner	No. of occu- pants	Inlet lpcd	Flush toilet		Bath/Shower		Laundry		Lawn water	
			lpcd	%inlet	lpcd	%inlet	lpcd	%inlet	lpd	%inlet
#1	5.0	161[a]	36.8	22.8	11.8	7.29	79.3	49.2	1340	62.4
#2	3.0	356[a]	105	29.4	29.9	8.40	35.6	10.0	1000	48.4
#3	4.0	166	44.0	26.5	8.71	5.30	--	--	--	--
#4	3.5	252	67.5	26.7	20.4	8.10	--	--	--	--
#5	2.7	260	111	42.5	46.3	17.8	--	--	--	--
#6	10.5	177	42.5	24.0	26.9	15.2	--	--	--	--
#7	5.0	133	34.4	25.9	15.5	11.7	34.0	25.7	--	--
#8	4.5	200	72.0	36.0	22.4	11.2	30.3	15.2	--	--
Overall Average		213	64.0	29.2	22.7	10.6	44.6	25.0	1170	55.4

[a] Inlet values shown = Total inlet - lawn water

The per capita water use data show considerable variation among the eight homes selected. Some of the more recent data published[5,6] correlated water consumption with such parameters as property valuation, education, income, occupation, etc. In the current program, the relatively small sample size precludes a meaningful evaluation of such relationships. The variability in the data, from one home to another, is largely a function of the difference in family habits and "life styles." Another significant factor appears to be the type of waste disposal used. The average total water consumption for the sewered homes was

Table 5. PHASE III - WATER CONSUMPTION DATA
(11/72 - 4/73)

Homeowner	No. of occupants	Inlet lpcd	Flush toilet		Bath/Shower		Laundry		Lawn water	
			lpcd	%inlet	lpcd	%inlet	lpcd	%inlet	lpd	%inlet
#1	8.2	121[a]	31.0	25.6	17.4	14.4	54.4	45.0	53.0	5.0
#2	2.0	432[a]	103	23.8	46.2	10.7	33.3	7.7	227	20.8
#3	4.0	144	36.4	25.3	14.0	9.70	--	--	--	--
#4	4.5	193	76.6	39.6	13.3	6.86	--	--	--	--
#5	2.3	267	116	43.4	33.7	12.6	--	--	--	--
#6	9.0	224	50.9	22.7	32.2	14.4	37.8	16.9	--	--
#7	5.0	153	50.9	33.1	35.6	23.2	28.8	18.8	--	--
#8	3.6	153	66.8	43.4	18.9	12.3	22.0	14.3	--	--
Overall Average		210	66.4	32.1	26.4	13.0	35.2	20.5	140	12.9

[a] Inlet values shown = Total inlet - lawn water

Table [illegible]. PHASES I & III - WATER CONSUMPTION DATA

Homeowner	No. of occupants	Inlet lpcd	Flush toilet		Bath/Shower		Laundry		Lawn Water	
			lpcd	%inlet	lpcd	%inlet	lpcd	%inlet	lpd	%inlet
#1	6.3	145[a]	34.4	23.8	14.0	9.68	69.0	47.6	811	47.0
#2	2.6	384[a]	104	27.1	36.0	9.37	34.8	9.10	714	41.6
#3	4.0	157	41.0	26.0	10.8	6.82	--	--	--	--
#4	4.0	220	72.5	32.8	16.6	7.51	--	--	--	--
#5	2.5	263	113	43.0	40.2	15.2	--	--	--	--
#6	10.0	190	44.8	23.6	28.4	15.0	37.8	20.0	--	--
#7	5.0	143	42.1	29.5	24.9	17.5	31.4	22.1	--	--
#8	4.1	179	69.8	38.9	20.8	11.6	26.5	11.6	--	--
Overall Average		210	65.2	30.6	23.8	11.6	39.8	19.1	763	44.3

[a] Inlet values shown = Total inlet - lawn water

253 lpcd, as compared with 167 lpcd for those connected to septic tanks. Although two of the eight test homes had non-metered water supplies prior to the test program, this was not found to be a meaningful parameter in this study in terms of correlating total water consumption.

A comparison of the test data with the results of a previous survey by General Dynamics reported in Reference 1 is shown in Table 7. The total (inlet) water consumption of 210 lpcd is only 13% less than the published figure and within the range of values commonly cited in the literature. The average water closet and bath consumption values, however, are considerably less than the results of the previous survey. Whereas Reference 1 reports toilet and bath usage as representing 39.2% and 31.4%, respectively, of total water usage, the test data for phases I & III show respective levels of 30.6% and 11.6%. On the other hand, laundry, and kitchen and lavatory usage are significantly higher than anticipated. The discrepancies noted probably reflect the different basis on which the data were collected. While the test data were based on suburban/rural single-family dwellings, the previous survey was probably more reflective of multiple-family dwellings within an urban setting.

Table 7. AVERAGE HOUSEHOLD WATER USE, TEST DATA (PHASES I AND III)

	No. of occupants	Inlet lpcd	Flush toilet		Bath/Shower		Laundry		Kitchen & lavatory	
			lpcd	%inlet	lpcd	%inlet	lpcd	%inlet	lpcd	%inlet
Test data	4.8	210[a]	65.1	30.6	23.8	11.6	39.8	19.1	68.3	29.4
Previous survey	4.0	242	95.0	39.2	75.9	31.4	33.1	13.8	37.8	15.7

[a] Outside uses included.

In order to facilitate subsequent statistical evaluation of the data in terms of each of the flow reduction devices tested, an additional tabulation was prepared (Table 8). The actual time periods covered in each home for Phases I and III are shown along with the mean per capita usage, and the standard deviations for the entire control period.

Table 8. STATISTICAL SUMMARY OF NORMAL WATER USE PATTERNS (For uses later modified by water saving devices)

A. **Flush toilet,** shallow trap, homes

	Phase I			Phase III			Phases I & III		
House-hold	Time Period	No. of days	lpcd	Time Period	No. of days	lpcd	No. of days	lpcd	S[a]
#1	5/14-12/22	180	36.8	12/27-5/2	28	37.1	208	36.8	5.3
#2	5/12-12/22	214	108	12/27-5/2	126	95.5	340	103	20.8
#3	4/30-11/7	191	44.0	12/24-4/28	119	36.4	310	41.4	6.9
#4	4/27-10/3	138	67.5	11/24-5/6	163	76.5	301	72.0	12.0
#5	4/26-10/22	165	111	11/22-5/1	156	116	321	113	15.9
#6	5/5-1/13	223	42.5	2/5-5/2	86	50.9	309	45.5	7.2

B. Sink-Bob homes

	Phase I			Phase III			Phases I & III		
House-hold	Time Period	No. of days	lpcd	Time Period	No. of days	lpcd	No. of days	lpcd	S
#2	5/12-12/22	214	74.6	--	--	--	214	74.6	14.2
#8	4/23-11/12	202	72.0	11/16-4/29	160	66.8	362	69.5	9.2

C. Econo-Flush homes

	Phase I			Phase III			Phases I & III		
House-hold	Time Period	No. of days	lpcd	Time Period	No. of days	lpcd	No. of days	lpcd	S
#2	5/12-12/22	214	74.6	--	--	--	214	74.6	14.2
#7	4/28-10/29	184	34.4	11/24-4/29	163	50.8	347	42.1	13.1

D. Flow limiting shower head homes

House-hold	Time Period	No. of days	lpcd	Time Period	No. of days	lpcd	No. of days	lpcd	S
#1	5/14-12/22	180	11.8	12/27-5/2	28	20.0	208	14.6	5.7
#2	--	--	--	12/27-5/2	126	46.3	126	46.3	5.1
#3	4/30-11/7	191	8.75	12/24-4/28	119	14.0	310	11.0	3.6
#4	4/27-10/3	138	20.4	11/24-5/6	163	13.3	301	16.2	4.6
#5	4/26-10/22	165	46.3	11/22-5/11	156	33.7	321	40.2	8.0
#6	5/5-1/13	223	26.8	2/5-5/2	86	32.2	309	28.6	4.4
#7	4/28-10/29	184	15.5	11/16-4/29	163	35.6	347	25.4	6.5
#8	4/23-11/12	202	22.4	11/16-4/29	160	18.9	362	20.9	7.6

[a] S = Standard deviation calculated from monthly averages.

The standard deviations for toilet consumption were computed on the basis of weekly average values. Bath water usage exhibited significantly greater irregularities, on a weekly basis. In order to obtain a more meaningful statistical analysis, monthly averages for bath usage were used for computation of the standard deviation in each household. The per capita usage data were obtained from Tables 4, 5, and 6, with some modifications required for homes #1 and #2 in order to obtain a meaningful comparison with Phase II data.

In home #1, the number of occupants changed abruptly from five to nine early in Phase III. The change was regarded as invalidating the family "identity" in terms of water use habits. Hence, only the data collected up to the time the change occurred (180 days + 28 days) were utilized. In home #2, a similar modification was made due to a decrease in the number of occupants from three to two which affected separately monitored toilets #2 and #3 in which the Sink-Bob and Econo-Flush devices were installed. Toilet #1 (shallow-trap toilet), used primarily by the two remaining occupants, was essentially unaffected by the change. Also, a radical change in bathing habits reported by homeowner #2 at the start of Phase II necessitated deletion of Phase I bath data for comparison purposes.

Significant long-term shifts in water use patterns, from Phase I through Phase III, are evident from a comparison of per capita bath water consumption. For toilet usage, relatively minor changes were the rule. In addition, bath water usage showed greater variability than water closet consumption based on relative deviations from the mean.

Hot and cold water service to the bath and clothes washing machine (laundry) was separately monitored and recorded throughout the test program. The data are presented in Table 9 for all three phases of the program, and will serve as the basis for an analysis of the savings in hot water usage (and associated fuel costs) effected by the flow limiting shower heads. Bath and laundry hot/cold water ratios are also tabulated for each household. A summary of all the data indicates that hot water represents 63% of bathing water consumption and only 43% of laundry water usage.

Table 9. HOT WATER VS. COLD WATER USAGE FOR BATH AND LAUNDRY, LPCD

Household	Phase I				Phase II				Phase III			
	Bath		Laundry		Bath		Laundry		Bath		Laundry	
	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold
#1	8.3	3.4	24.2	54.9	12.5	3.8	26.5	48.1	15.5	4.5	28.0	26.1
#2	14.6	19.3	9.8	25.7	13.2	22.3	9.5	26.5	18.2	27.3	11.7	21.6
#3	4.5	3.4	--	--	4.9	4.2	--	--	7.6	6.4	--	--
#4	10.2	10.2	--	--	8.7	4.18	--	--	8.7	4.6	--	--
#5	23.1	23.1	--	--	18.2	15.5	--	--	23.8	9.8	--	--
#6	18.6	13.6	--	--	16.7	6.8	27.6	25.4	23.5	8.4	17.4	21.6
#7	7.6	7.6	19.3	14.8	13.6	12.5	17.8	14.4	23.1	14.0	15.9	12.1
#8	15.2	7.2	11.7	18.6	18.9	8.3	14.0	22.8	13.3	5.7	8.3	13.2
Overall Average Ratios	1.35		0.69		1.77		0.77		2.03		0.87	

SECTION V

BATHROOM FLOW REDUCTION DEVICES: SELECTION, INSTALLATION AND PERFORMANCE

TOILET FLUSHING REQUIREMENTS

According to toilet consumption data reported in Reference 1, flushing accounts for a major fraction of the total household water requirements, ranging from 30% to 40%. However, despite the recent emphasis on water and waste management in this country, cleaning action and appearance are considered at least as important as water consumption. The predominant type of flushing action when a tank is used is the siphon jet type. When flushing occurs, a jet of water is activated under the water level creating a siphon action which cleans out the bowl. The average consumption for each flushing action is approximately 20 liters (5.3 gal.), a substantial portion of which is involved in the bowl cleaning function. Another common toilet design is the reverse trap type. The flushing action and general appearance of the reverse trap bowl is similar to the siphon jet. The water surface and size of trapway are smaller, however, and the depth of seal is less.

Two distinct approaches have been implemented in this program in an attempt to reduce toilet flushing requirements in a manner consistent with homeowner acceptability. The approaches, described below, are: (a) shallow trap toilets and (b) dual cycle flush devices.

SHALLOW TRAP TOILET

One of the approaches involved the use of a water saving toilet designed to use approximately one-third less water than ordinary toilets. The specific model selected for testing was the American Standard Water Saving Elongated Cadet, shown in Figure 4. It is similar in appearance and cost to the standard model except for a noticeably smaller tank. Less water is required for flushing due to the special design of the bowl (shallower trap). The Crane Company manufacturers a toilet similar in design and flush volume called the Radcliffe Water Miser. This toilet was not tested due to availability problems relative to our program schedule.

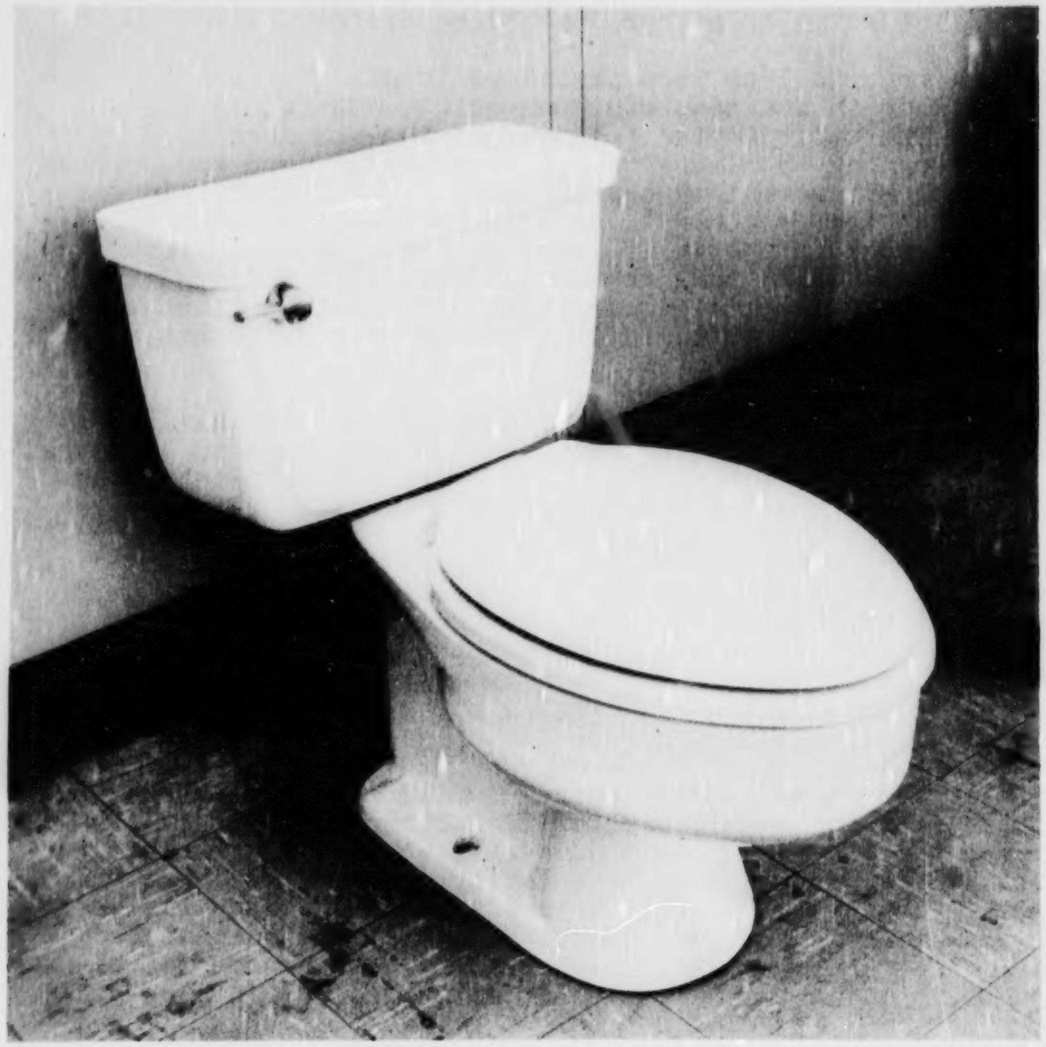

Figure 4. Shallow trap toilet

The original plan called for the incorporation, inside the toilet tank, of one of the dual flush devices described below. However, preliminary testing indicated that this was not possible because (a) the shallow trap toilet would not operate properly with a reduced flush (less than 11.5 liters), and (b) the unique design of the toilet flush valve precluded insertion of either dual flush device.

Shallow trap toilets were installed in six of the eight test homes, four in southeastern Connecticut and two in San Diego. The water saving toilets had the standard 30.4 cm (12") roughing-in dimension and no problems were encountered by the plumbing contractors in their installation. In each case, the float arm had to be bent downwards substantially in order to keep the water level at the prescribed mark. The maximum inflow rate to the tank was also adjusted in order to provide an adequate flush with minimum flush volumes. The entire installation, including adjustments, averaged about 30 minutes.

Flush volumes actually used for each of the six shallow trap toilets are presented in Table 10 and compared with the flush volumes of the original, conventional toilets. Initial flush volumes for the water saving toilets ranged from 9.5 to 12.5 liters, representing an average flush volume reduction of 24%. Two of the toilets (homes #5 and #6) required follow-up adjustments due to double flushing problems noted by the homeowners. Several field adjustments had to be made at home #5. Recurrence of the flushing problem was finally traced to a defective flush valve (metering type) which was closing prematurely. Repair of the flush valve corrected the flushing problem. The double flushing reported in home #6 was found to be related to the wash water recycle system installed in that home for toilet flushing. This was verified by temporarily switching to the city water supply, during which time the shallow trap toilet performed satisfactorily. After switching from a cartridge to a diatomite filter system, and doubling the capacity of the pressure tank, the toilet was reconnected to the recycle system and satisfactory performance was obtained for the remainder of the test period.

DUAL FLUSH TOILET DEVICES

The second approach utilized devices which converted a conventional water closet to dual cycle operation, i.e., a short flush for liquids and a normal flush for solids. Three different devices were examined during the program,

Table 10. COMPARISON OF WATER CLOSET FLUSH VOLUMES

Home	Number of baths	Conventional toilet flush vol., liters	Shallow Trap toilet flush vol., liters	Sink-Bob flush vol., liters		Econo-Flush flush vol., liters	
				Light	Normal	Light	Normal
1	1	17.2	11.4	--	--	--	--
2	3	14.8/16.3/ 16.7	12.1	8.0/ 8.7	16.7/ 17.0	14.4/ 14.0	17.1/ 17.8
3	1	12.5	9.5	--	--	--	--
4	1	16.3/20.8	12.1	--	--	--	--
5	1	14.4	12.5-14.4	--	--	--	--
6	1	17.9	11.4-12.9	--	--	--	--
7	2	13.6/17.0	--	--	--	10.6/ 14.0	14.0/ 17.1
8	1½	15.5/15.5	--	7.6/ 8.0	16.7/ 15.5	--	--

the Econo-Flush, the Sink-Bob, and the Saveit. Although similar in effect, all the devices differed substantially in design, and are described below. Water consumptions with the Sink-Bob and Econo-Flush were shown previously in Table 10.

Econo-Flush

This toilet device consists of two interconnected plastic tanks open at the bottom which are positioned inside the toilet tank, and a handle/lever assembly incorporating a unique valve arrangement. A picture of the assembled device is shown in Figure 5. With the exception of some of the newer toilet models (American Standard, Sears), which have special flush valves, most standard models with standard flush valves will accommodate this particular device. The Econo-Flush operates in the following manner:

(a) Light flush - This is activated by pushing the handle up. The handle assembly, through a unique linkage arrangement, simultaneously opens the toilet flush valve and closes a plastic valve which seals both plastic tanks from the atmosphere. The contents of both tanks (approximately one gallon) are thereby trapped by the vacuum created and a reduced flush results.

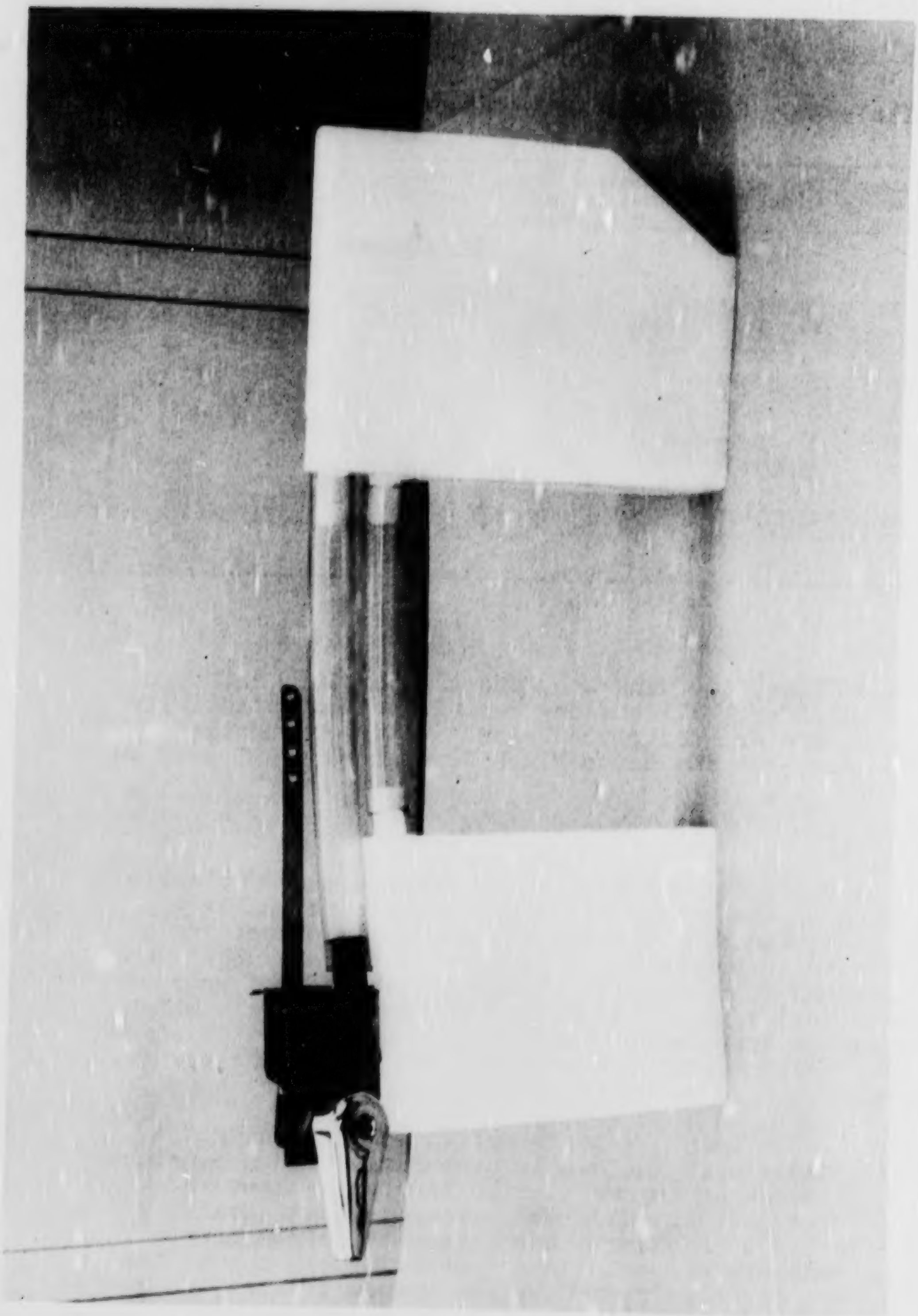

Figure 5. Econo-Flush toilet device

(b) Normal flush - This is activated by pushing the handle down in the usual manner. The plastic valve now opens in conjunction with the toilet flush valve, breaks the vacuum seal and thereby allows a full flush to occur.

A label is included for posting on or near the toilet in order to remind the household occupant of the new flushing procedure.

Sink-Bob

As shown in Figure 6, this dual flush device consists of a polystyrene float and lead sinker connected to the float stem by a split brass ring. As with the Econo-Flush device, most standard toilet models will accommodate the Sink-Bob. The Sink-Bob attaches to both rod and flapper-type seals at a point just above the flush valve. The device operates in the following manner:

(a) Light flush - The toilet handle is tripped in the normal manner, opening the flush valve and allowing the water in the closet tank to drain into the bowl. When the level inside the tank has decreased by approximately 50%, the Sink-Bob attains sufficient negative buoyancy to prematurely seat the flush valve.

(b) Normal flush - For full flush, the handle must be held down during the entire flushing operation to prevent premature closing of the flush valve.

Saveit Water Saver

The Saveit water saver, unlike the other devices described above, will not convert a toilet to dual-cycle operation without modification. It does provide a reduced flush of approximately 50% in a manner similar to that of the Sink-Bob. The device consists of a pre-folded plastic sheet which is formed around the flush valve and secured with two anchor rods (see Figure 7). When flushing occurs, the flush valve closes prematurely as approximately one-half of the water in the tank is blocked from gaining access to the drain.

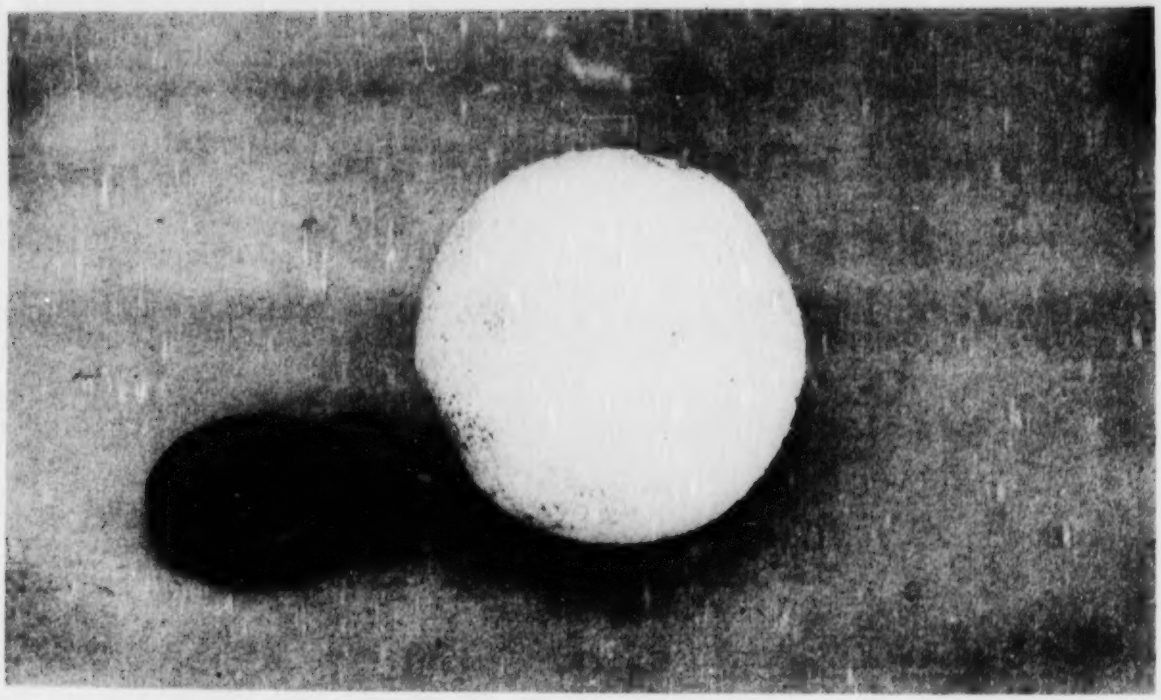

Figure 6. Sink-Bob toilet device

Home Installation

Dual-flush toilet devices were installed in homes #2, #7, and #8. Four Econo-Flush units were installed; two in home #7 for one year, and two in home #2 for a six-month period. In home #2, installation was performed by the homeowner in about 15 to 20 minutes. A slight increase in normal flush volumes was observed due to slight adjustments to the float rod necessitated by the presence of the plastic tank inserts. In home #7, due to a special toilet flush valve arrangement, the new trip lever assembly had to be modified accordingly (see Figure 8). In addition, some minor alterations were required in the float rod orientation. In both homes, the dual-flush modification provided a light flush volume nearly 3.8 liters less than the normal flush volume.

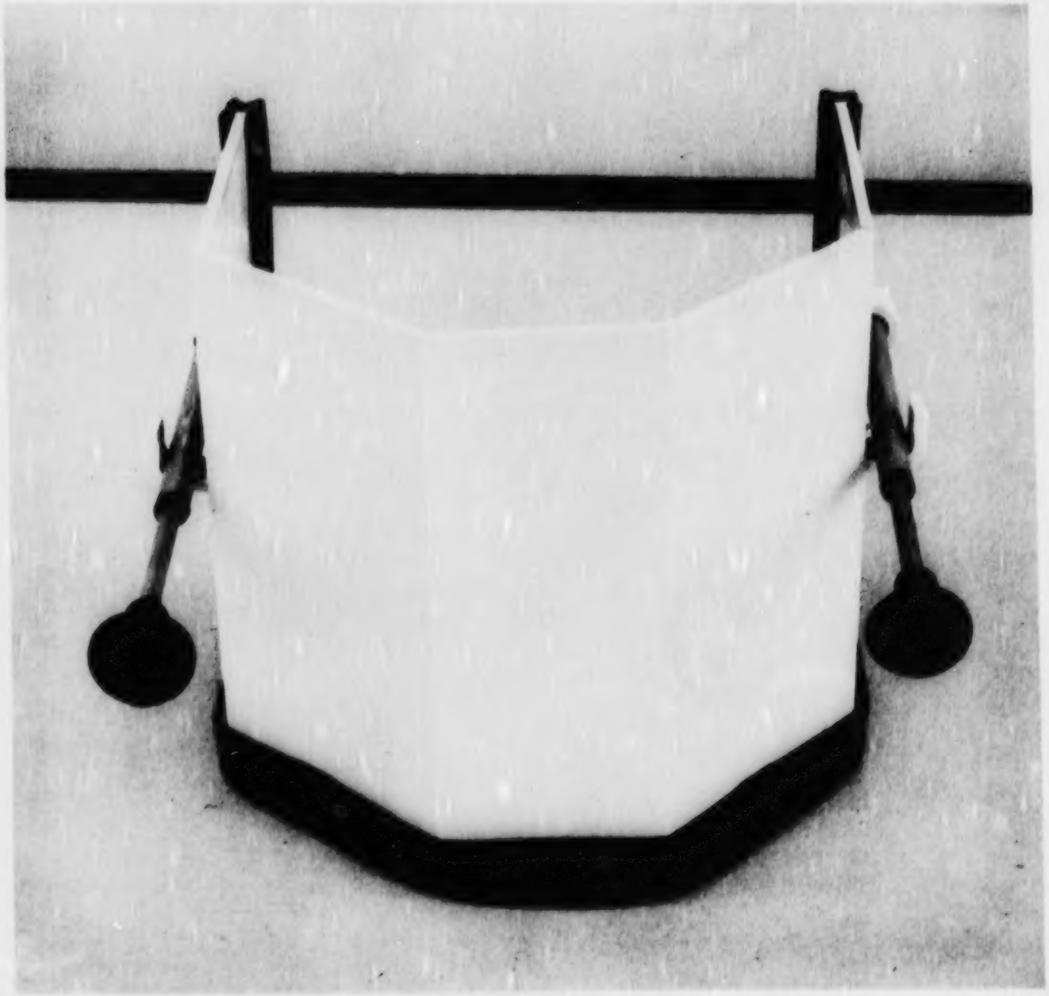

Figure 7. Saveit toilet device

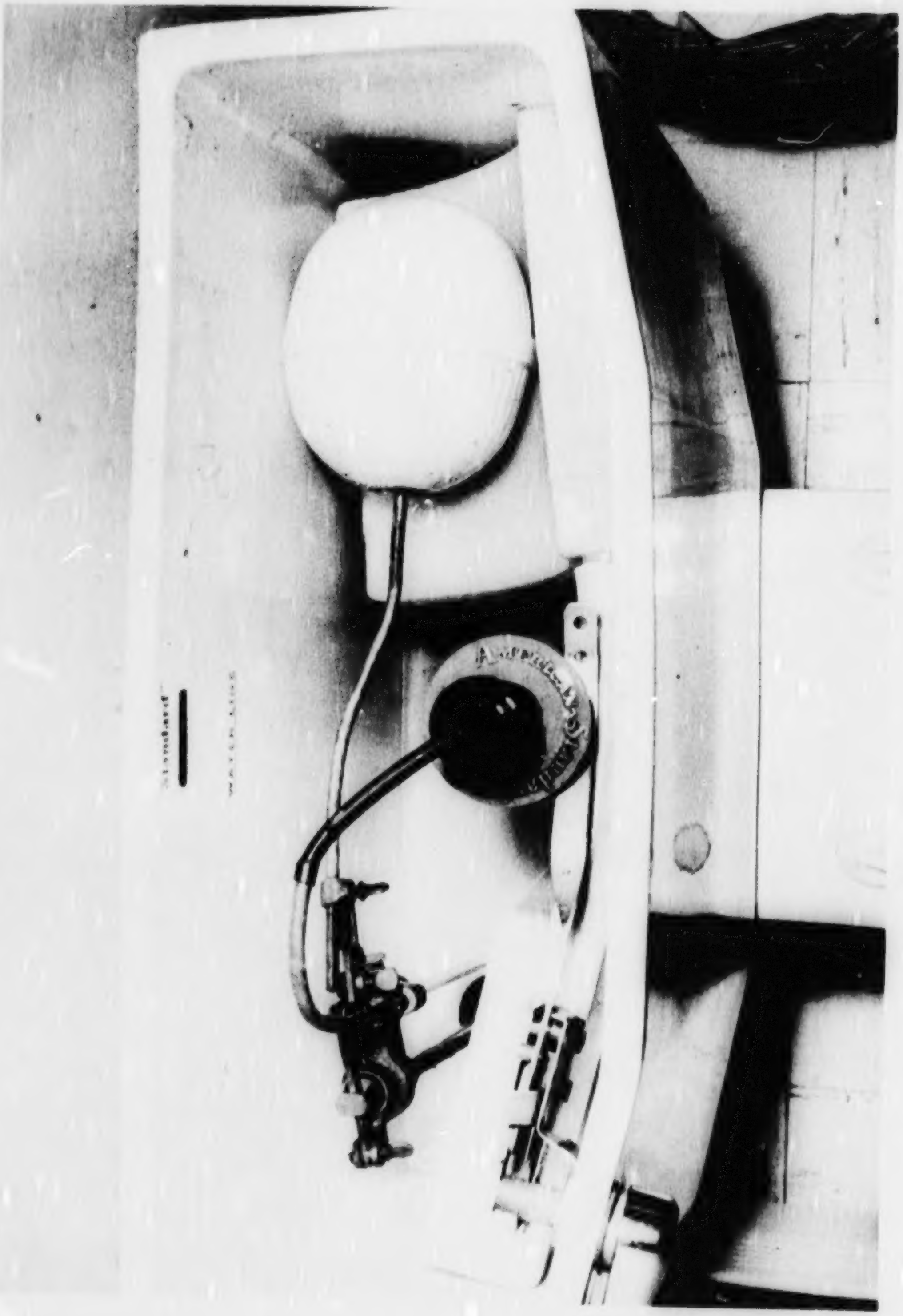

Figure 8. Econo-Flush toilet device: installed

In order to correct occasional binding of the handle which occurred after light flush tripping of one of the toilets in home #7, the handle assembly was removed and lubricated with Teflon spray. Subsequent flushing problems in home #7 were related to intermittent clogging of the inlet valves with recycled water solids, and traced to the flow restrictive design of the downcomer tube. Replacement of both inlet valves with valves of newer, more modern design corrected the problem.

Four Sink-Bob units were installed, two in home #8 for one year, and two in home #2 for a six-month period. Installations of all units were accomplished by the homeowners in approximately 3 to 5 minutes, without any modifications required. In home #2 the Sink-Bobs were attached to rod-type flush valves; in home #8 the devices were attached to flapper valves. In the light flush mode, flush volumes were reduced by about 50%.

The Saveit toilet device was installed in two homes not connected with the test program for a preliminary qualitative evaluation. The installation was readily performed by the homeowner in about 5 minutes. As noted above, the Saveit device is not a dual-flush device, and provides a reduced flush only. In one of the toilets, the device did not provide an adequate flush for solids. The Saveit was subsequently modified for dual flush operation by removing a small semi-circular section at the base of the unit, and operated satisfactorily thereafter. The light flush was achieved by depressing and releasing the toilet handle in the normal manner. For a full flush it was necessary to keep the handle down until the toilet tank had been completely emptied. For the last two months of Phase II, the modified Saveit was installed in home #7 (see Figure 9) for a limited qualitative comparison with the Econo-Flush device. The modified device provided a flush reduction of about 4.8 liters (similar to the Econo-Flush). Because of the limited use of the Saveit, results with this device are not included in the summary tables elsewhere in this report.

FLOW LIMITING SHOWER HEADS

Published surveys of water usage (references 1 and 5) indicate that approximately 30% of the total household water consumption is used for bathing. It is interesting to note the disparity between this value and the overall average usage recorded during Phases I and III of approximately 12%. This points to the possibility that the group of eight families selected are atypical with respect to bathing patterns (lower than average bathing frequency). They

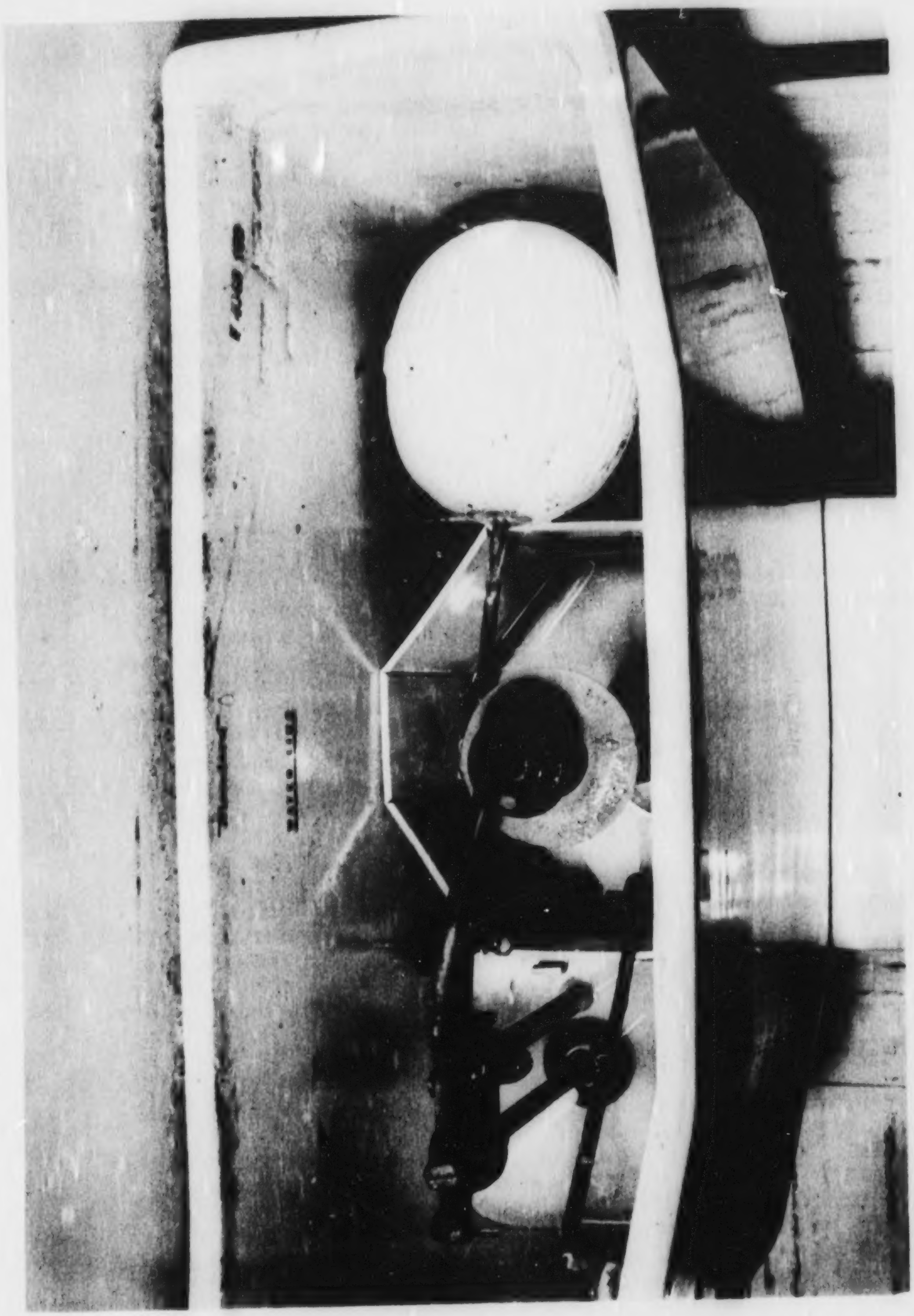

Figure 9. Saveit toilet device: installed

also seemed to have a greater preference for tub baths than showers.

Shower heads with built-in flow limiting orifices are available which can reduce water consumption rates from the typical 19 to 38 lpm (5 to 10 gpm) to 9.5 or 13.3 lpm (2.5 to 3.5 gpm). The actual amount of water saved will depend primarily on the system water pressure and the personal habits of the bather. Two different Speakman flow limiting shower heads were selected for testing. The first of these, shown in Figure 10, is equipped with a 13.3 lpm integral "Auto-flo" flow limiting orifice. This shower head has a fully-adjustable spray, integral ball joint and a 5 cm face. The second shower head, shown in Figure 11, is equipped with a 9.5 lpm integral "Auto-flo" limiting orifice. It is also of the adjustable spray, ball joint type but has a much narrower shape. Both shower heads have standard 1.27 cm (1/2") I.P.S. female inlets which are compatible with standard shower arms. A total of eleven flow limiting shower heads were installed in the eight test homes, with the specific distribution shown previously in Table 2. Installation can be performed by a homeowner in about 5 minutes.

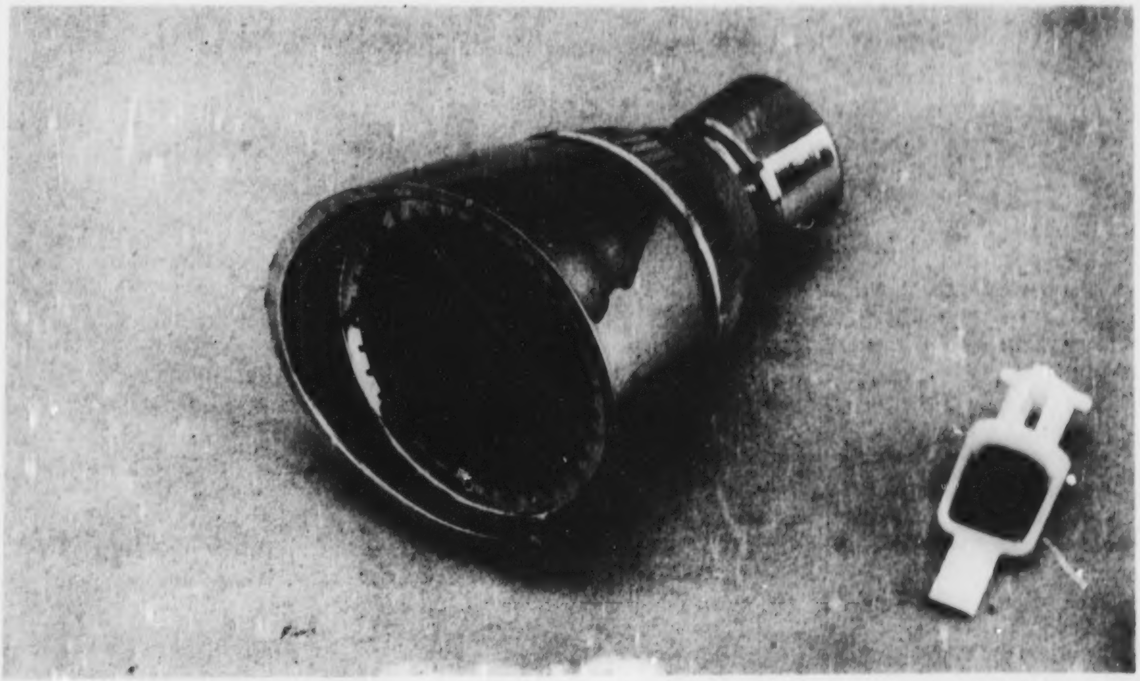

Figure 10. Speakman Auto-flo shower head: 13.3 lpm

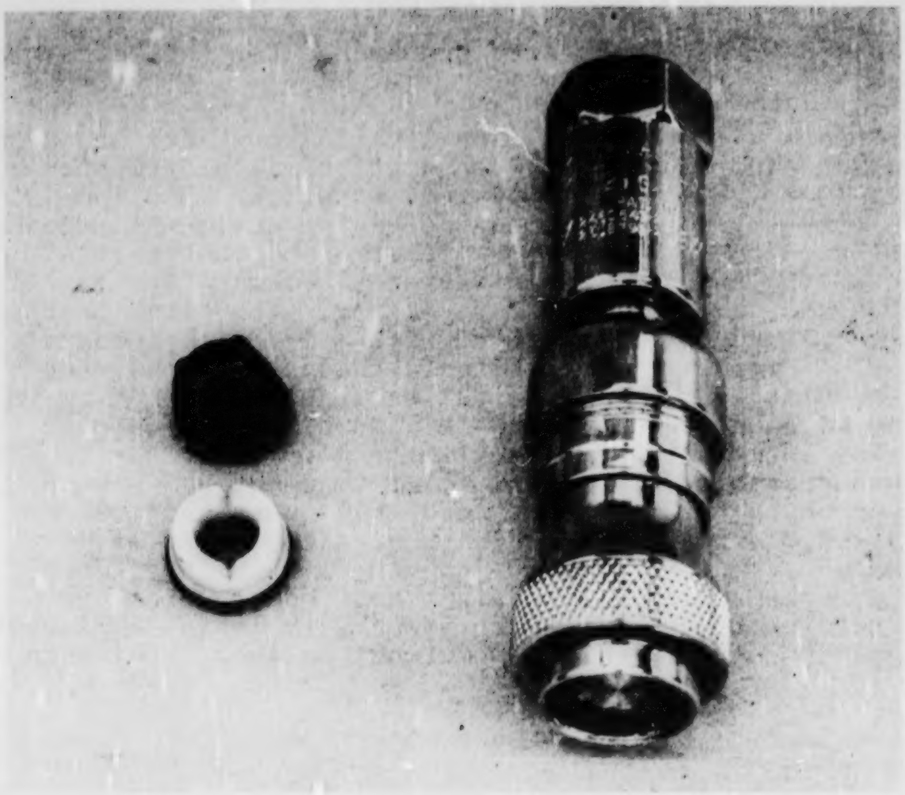

Figure 11. Speakman Auto-flow shower head: 9.5 lpm

WATER METERS

Pre-calibrated, domestic-type water meters were used for monitoring total water consumption as well as water used for toilet flushing, bathing, laundering and lawn sprinkling as indicated before in Figures 1 and 2. Neptune Tri-Seal split-case meters, 1.59 cm (5/8") size, were selected for all cold water lines, and Neptune Trident Type S meters were used for all hot water lines (bath and laundry). Both meters provide very close to 100% accuracy from 0.94 lpm to 75 lpm and beyond, and produce a negligible pressure drop over the range of interest for all fixtures monitored. The meter registers were calibrated in gallons, and could be read to the nearest tenth of a gallon.

TEST PERIOD WATER CONSUMPTION DATA

Daily average water use values are presented in Table 11 on a per capita basis for all eight test homes. The data cover roughly a one-year period from November 1971 to November 1972. In Table 12, the data have been recast in a more convenient form for evaluation of water savings and statistical analyses. The actual time periods covered are shown along with the mean per capita usage and corresponding standard deviations. As noted in Section IV, the standard deviation for water closet consumption and bath usage were computed on the basis of weekly averages and monthly averages, respectively.

Table 11. TEST PERIOD WATER CONSUMPTION DATA (PHASE II)

Homeowner	No. of occupants	Inlet lpcd	Flush toilet		Bath/Shower		Laundry		Lawn water	
			lpcd	%inlet	lpcd	%inlet	lpcd	%inlet	lpcd	%inlet
1	5.2	136[a]	20.4	15.0	16.1	11.8	74.8	54.7	1520	68.0
2	2.5	300[a]	82.3	27.4	35.9	12.0	36.0	12.0	497	39.8
3	4.1	149	35.6	23.9	9.1	6.1	--	--	--	--
4	3.4	172	50.0	29.1	14.4	8.4	--	--	--	--
5	2.4	260	103	43.2	32.2	12.4	--	--	--	--
6	9.9	195	27.6	14.2	23.8	12.3	53.0	27.2	--	--
7	5.0	99.8	39.4	39.5	25.8	25.9	32.2	32.3	--	--
8	4.1	117	47.5	40.5	27.6	23.7	36.8	31.5	--	--
Overall Average		178	52.0	29.1	23.1	14.1	46.6	31.5	1010	53.9

[a] Inlet values shown = Total inlet - lawn water.

In home #2, Econo-Flush dual-flush devices were tested for a period of eight months in water closet #2 and #3. The Econo-Flush devices were then replaced by two Sink-Bobs for a comparative evaluation. However, as indicated in Table 12, only 31 days of testing were completed. This was because the primary user of water closet #2 and #3 vacated the home for the remainder of Phase II.

Table 12. STATISTICAL SUMMARY OF WATER USE PATTERNS DURING TEST PERIOD (PHASE II)

	Household	Time period	No. of days	lpcd	S[a]
A.	Shallow Trap Toilet				
	1	1/5 - 12/20	328	20.6	3.14
	2	1/6 - 12/27	309	76.3	10.1
	3	11/13 - 11/25	378	35.6	4.55
	4	10/29 - 10/27	356	50.0	7.97
	5	11/7 - 11/19	342	113	17.4
	6	1/13 - 12/4	290	27.6	6.07
B.	Sink-Bob				
	2	9/27 - 11/1	31	55.8	12.0
	8	10/4 - 11/12	363	47.4	8.8
C.	Econo-Flush				
	2	1/6 - 9/13	215	49.8	13.2
	7	10/29 - 11/22	387	39.4	6.1
D.	Flow Limiting Shower Heads				
	1	1/5 - 12/20	328	16.1	3.0
	2	1/6 - 12/27	309	35.8	6.1
	3	11/13 - 11/25	378	10.1	2.0
	4	10/29 - 10/27	356	14.6	3.1
	5	11/7 - 11/19	342	32.2	6.9
	6	1/13 - 12/4	321	23.8	3.7
	7	10/29 - 11/22	387	25.8	5.9
	8	10/4 - 11/12	363	27.6	10.3

[a] S = Standard deviation

Statistical Analysis

Prior to a comparison of test and control period data, a statistical analysis was performed to determine whether or not the differences between the mean values being compared (water savings) were statistically significant. For this analysis, the student's t-distribution was used to test the null hypothesis: $\bar{X}_1 - \bar{X}_2 = 0$. The t-distribution is a measure of the deviation between the means of two random groups of data. The specific values of t were calculated from the following equation[7]:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{(n_1 S_1^2 + n_2 S_2^2)^{\frac{1}{2}}} \left[\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}\right]^{\frac{1}{2}}$$

where:

$\bar{X}_1$ = mean usage, control period

$\bar{X}_2$ = mean usage, test period

S_1 = standard deviation, control period

S_2 = standard deviation, test period

n_1 = number of data points, control period

n_2 = number of data points, test period

The calculated values of t were compared with the theoretical values of t at $P = 0.05$ (95% confidence level) in Table 13 at the corresponding number of degrees of freedom $(n_1 + n_2 - 1)$. The decision to reject the null hypothesis (equivalent to a confirmation of statistical significance at the 95% confidence level) was made when the calculated value of t was found to be greater than the theoretical value.

For the shallow trap toilets, the null hypothesis was rejected in five of the six homes. In home #5, the means were statistically indistinguishable as the average values were, in fact, identical. As for the dual-flush devices, both sets of data for the Sink-Bobs received statistical confirmation, while only one set of Econo-Flush data was found to be statistically significant. In the other set (home #7) the control period standard deviation is seen to be excessively large relative to the rather small difference in means observed.

Table 13. STATISTICAL SIGNIFICANCE OF INDIVIDUAL WATER SAVINGS

		Control period data (Phases I & III)			Test period data (Phase II)			Student's t - test		
	Household	$\bar{X}_1$, lpcd	Standard deviation	N_1	$\bar{X}_2$, lpcd	Standard deviation	N_2	$t_{calc.}$	t at $P = 0.05$	$H_0: = \bar{X}_1 - \bar{X}_2 = 0$
Shallow trap Toilet	1	36.8	5.3	31	20.6	3.1	47	16.7	1.99	Reject
	2	103	20.8	45	76.3	10.1	44	7.5	1.98	Reject
	3	41.4	6.9	41	35.6	4.5	25	3.7	2.00	Reject
	4	72.0	12.0	30	50.0	7.9	40	9.1	1.99	Reject
	5	113	15.9	39	113	17.4	48	0.0	1.99	Accept
	6	45.5	7.2	35	27.6	6.0	36	11.2	1.99	Reject
Sink-bob	2	74.6	14.2	27	55.8	12.0	4	2.43	2.04	Reject
	8	69.5	9.2	37	47.4	8.8	28	9.6	2.00	Reject
Econo flush	2	74.6	14.2	27	49.8	13.2	13	5.1	2.02	Reject
	7	42.1	13.1	37	39.4	6.1	26	0.96	2.00	Accept
Flow limiting shower heads	1	14.6	5.7	9	16.1	3.0	12	0.74	2.12	Accept
	2	46.3	5.1	6	35.8	6.1	12	3.4	2.46	Reject
	3	11.0	3.6	12	10.1	2.0	12	0.73	2.39	Accept
	4	16.2	4.6	11	14.6	3.1	12	0.94	2.40	Accept
	5	40.2	8.0	12	32.2	6.9	12	2.51	2.39	Reject
	6	28.6	4.4	12	23.8	3.7	11	2.69	2.40	Reject
	7	25.4	6.5	12	25.8	5.9	12	0.15	2.39	Accept
	8	20.9	7.6	12	27.6	10.3	12	1.74	2.39	Accept

NOTE: The decision to reject is equivalent to a confirmation of statistical significance.

In only three of the eight homes using flow limiting shower heads (#2, #5, and #6) were the data found to be statistically significant. In those cases for which the null hypothesis was accepted, any observed differences in average water use (positive or negative) will be set equal to zero.

WATER SAVINGS

Bathroom Flow Reduction Devices

Conventional toilets were replaced by shallow trap toilets in six of the eight test homes. The water saving toilets were advertised as consuming approximately one-third less water for flushing then conventional toilets. Actual measured flush volume reductions (as shown previously in Table 10) averaged 25%, ranging from 7% to 35%.

Table 14 shows the actual water savings in each of the six homes. In general, the percentage reduction in water usage correlated fairly well with the measured flush volume reductions, ranging from 0% to 44%, with an average reduction of 25.6%. This indicates that the toilets operated dependably. Water savings ranged from 0 to 26.7 lpcd, with an average savings of 14.8 lpcd. The percentage reduction in total water usage averaged 6.9%, with the maximum value of 11.2% attained in home #1.

Table 14. WATER SAVINGS OBTAINED WITH SHALLOW TRAP FLUSH TOILET

	Conventional toilet		Shallow trap toilet		Water savings		% reduction in total water usage
Household	No. of occupants	lpcd	No. of occupants	lpcd	lpcd	% reduction	
1	5.1	36.8	5.2	20.6	16.2	44.0	11.2
2	2.0	103	2.0	76.3	26.7	26.1	7.0
3	4.0	41.4	4.1	35.6	5.8	14.0	3.7
4	4.0	72.0	3.4	50.0	22.0	30.6	10.0
5	2.5	113	2.4	113	0	0	0
6	10.1	45.5	9.9	27.6	17.9	38.8	9.4
			Average savings		14.8	25.6	6.9

In three of the test homes, six toilets were modified for dual cycle operation by either the Sink-Bob or Econo-Flush toilet inserts. The Sink-Bob and Econo-Flush devices provide respective reductions of approximately 50% and 25% respectively when operated in the light flush mode. The overall reduction in water consumption will depend on how often the light flush is used as well as the adequacy of bowl cleaning by the light flush.

Table 15 presents the water savings actually obtained over the one-year test period. The Sink-Bob devices performed well in both homes #2 and #8, resulting in an average water savings of 20.5 lpcd, equivalent to an average reduction in toilet flushing of 28.6%. The Econo-Flush device gave better than anticipated results in home #2, but proved ineffective in home #7. The insignificant water savings in the latter home was partially attributable to a relaxation of toilet flushing habits (failure to use the reduced flush) due to the recycle system installation and the resulting abundance of wash water for toilet flushing. Another significant factor was the relative infrequency of light flush usage by the three children. Average savings for the Econo-Flush was 12.4 lpcd (16.6%). The overall average water savings for both dual flush devices was 16.5 lpcd (22.6%). The percentage reduction in total water usage averaged 6.0%.

Eleven flow limiting shower heads were installed in the eight test homes. As noted earlier, two different types were employed. In five of the homes, 13.3 lpm flow limiting shower heads were used, and 9.5 lpm shower heads were used in the remaining three. The water savings produced by these devices are shown in Table 16. As indicated in Table 13, in only three of the homes (#2, #5, and #6) were the data found to be statistically significant. In the remaining five homes, the mean usage values (test vs. control) were found to be statistically indistinguishable. In general, the observed lack of effectiveness appears to be primarily a function of personal bathing habits. In four of the homes (#1, #3, #4, and #7), significant shifts in bathing frequency and/or habits from Phase I to Phase III were observed (see Table 8). In homes #3 and #4, showering accounted for only a minor fraction of all bathing activity. An overall average water savings of only 2.7 lpcd, corresponding to a percentage reduction of 7.1% was observed. The percentage reduction in total water usage was only 1.0%.

Table 15. WATER SAVINGS OBTAINED WITH DUAL FLUSH DEVICES

Household	Conventional Toilet		Dual flush devices				Water Savings					
			Sink bob		Econo-flush		Sink-bob			Econo-flush		
	No. of occupants	lpcd	No. of occupants	lpcd	No. of occupants	lpcd	lpcd	% Reduc. of Flush	% Reduc. of total	lpcd	% Reduc. of Flush	% Reduc. of total
2	1.5	74.6	1.5	55.8	1.5	49.8	18.8	25.2	4.9	24.8	33.2	6.5
7[a]	5.0	42.1	---	---	5.0	39.4	---	---	---	2.7[a]	6.4[a]	1.9[a]
8	4.1	69.5	4.1	47.4	---	---	22.1	32.0	12.3	---	---	---
						Average savings	20.5	28.6	8.6	12.4	16.6	3.3

	lpcd	% Reduction of Flush	% Reduction of total
Overall average savings	16.5	22.6	6.0

---

[a] Water savings set = 0 based on statistical analyses

Table 16. WATER SAVINGS OBTAINED WITH FLOW LIMITING SHOWER HEADS

Household	Conventional shower heads		Flow limiting shower heads				Water savings					
			13.3 lpm		9.5 lpm		13.3 lpm			9.5 lpm		
	No. of occupants	lpcd	No. of occupants	lpcd	No. of occupants	lpcd	lpcd	% Redu. of bathing	% Red. of total	lpcd	% Redu. of bathing	% Red. of total
1[a]	5.1	14.6	5.2	16.1	---	---	-1.5	-10.3	-1.0	---	---	---
2	2.7	46.3	2.5	35.8	---	---	10.5	22.7	2.8	---	---	---
3[a]	4.0	11.0	---	---	4.1	10.1	---	---	---	0.9	8.2	0.6
4[a]	4.0	16.2	---	---	3.4	14.6	---	---	---	1.6	9.9	0.7
5	2.5	40.2	2.4	32.2	---	---	8.0	19.9	3.1	---	---	---
6	10.1	28.6	---	---	9.9	23.8	---	---	---	4.8	16.8	2.5
7[a]	5.0	25.4	5.0	25.8	---	---	-0.4	-1.6	-0.3	---	---	---
8	4.1	20.9	4.1	27.6	---	---	-6.8	-32.5	-3.8	---	---	---
						Average savings	3.7	8.5	1.2	1.6	5.6	0.8
							lpcd		% Redu. of bathing		% Redu. of total	
						Overall avg. savings	2.7		7.1		1.0	

[a] Water savings considered statistically insignificant (set = 0) for calc. of average savings.

Shower hot water savings, presented in Table 17, ranged from 0 to 5.2 lpcd (0 to 21.8% reduction), with an average savings of 1.5 lpcd (7.2% reduction in shower hot water usage). Evaluation of the shower hot water savings was based on the same statistical considerations as were applied to the data in Table 16.

Table 17. SHOWER HOT WATER SAVINGS

Household	**Phases I & III** lpcd	Phase II lpcd	Hot water savings lpcd	Hot water savings % reduction
1[a]	12.2	12.5	-0.3	-2.5
2	16.1	13.2	2.9	18.0
3[a]	5.7	4.9	0.8	14.0
4[a]	9.4	8.7	0.7	7.5
5	23.4	18.2	5.2	21.8
6	20.2	16.7	3.5	17.3
7[a]	14.9	13.6	1.3	8.7
8[a]	14.4	18.9	-4.5	-31.0
		Average savings	1.5	7.2

[a] Hot water savings in these homes set equal to zero based on results of statistical analysis summarized in Table 12.

SECTION VI

RECYCLE SYSTEMS: DESIGN, DEVELOPMENT INSTALLATION AND PERFORMANCE

OVERALL SYSTEM DESIGN, INSTALLATION AND PERFORMANCE

Treatment, Storage and Toilet Flushing Reuse

Since toilet flushing normally accounts for the major fraction (30-40%) of household water usage, the reuse of waste wash waters (bath and laundry) for this function is a potentially attractive scheme. The actual amount of water saved will depend upon the nature of the balance between waste wash water generated and toilet usage in a particular household. If necessary, a more favorable balance can be effected by (a) a reduction in toilet flushing requirements through installation of a suitable dual-flush device, or (b) an increase in the available supply by inclusion of lavoratory waste water.

Apart from the necessity of providing an adequate water supply at all times, other desirable system criteria include minimum odor, minimum staining properties, acceptable clarity and color, and prevention of health hazards. It is, of course, also necessary to achieve these criteria under the practical constraints of acceptable costs, maintenance, and space requirements. One of the aims of this program was to develop sufficient information with which to establish an acceptable compromise in terms of performance, cost, and safety.

All of the functions and components involved in the household wash water recycle systems are illustrated in Figures 12 and 13. These configurations are the ones chosen for extended testing after optimization of component choice and arrangement. The prior development work and individual component performance are described in more detail in later subsections of this chapter. Both systems finally chosen are fundamentally similar with the exception of the specific design of the filtration and disinfection systems. The recycle system incorporating the diatomite filter

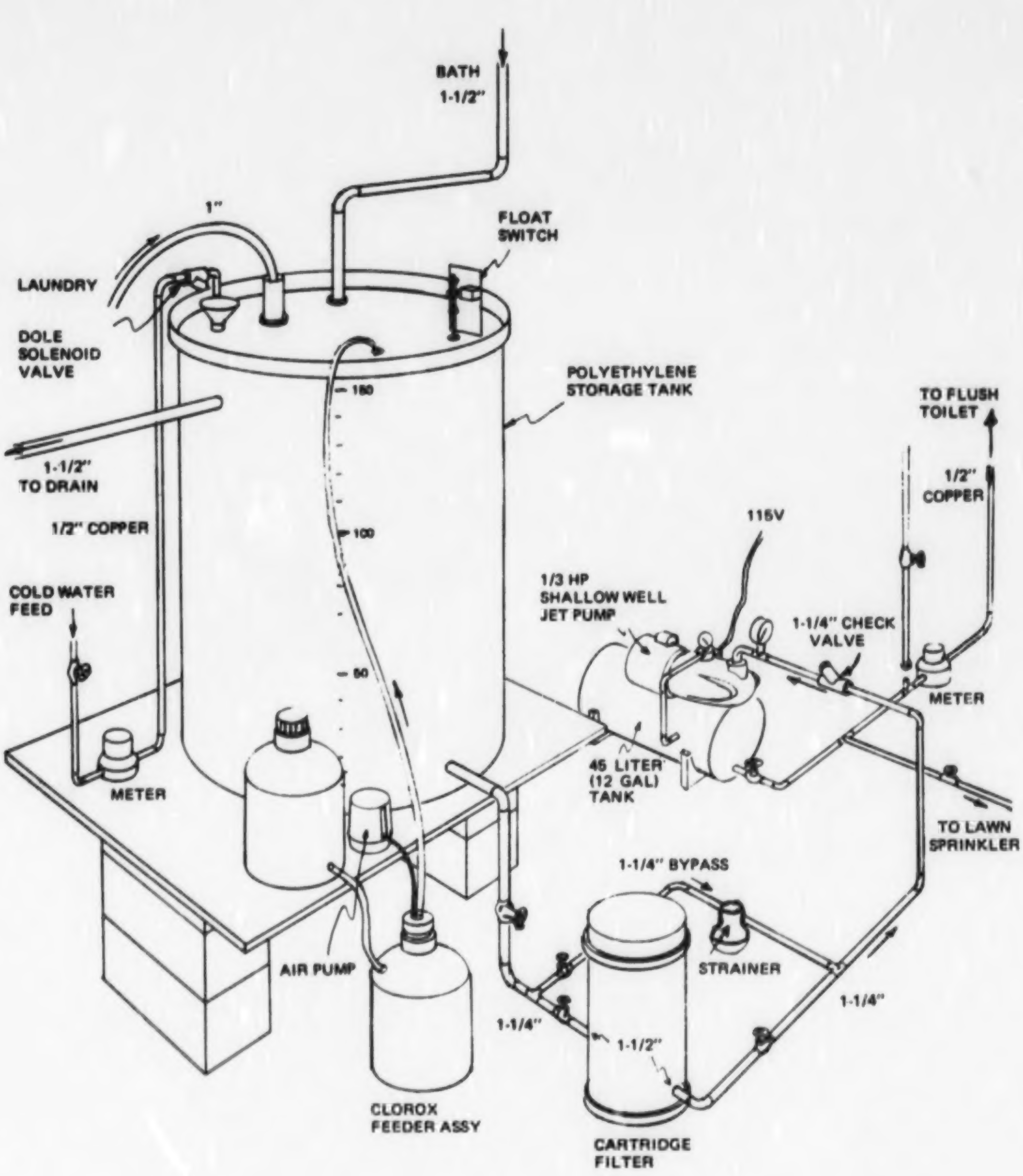
BATH
1-1/2"
1"
FLOAT SWITCH
LAUNDRY
DOLE SOLENOID VALVE
150
POLYETHYLENE STORAGE TANK
TO FLUSH TOILET
1-1/2" TO DRAIN
1/2" COPPER
1/2" COPPER
100
115V
COLD WATER FEED
1/3 HP SHALLOW WELL JET PUMP
1-1/4" CHECK VALVE
50
METER
METER
45 LITER (12 GAL) TANK
TO LAWN SPRINKLER
1-1/4" BYPASS
AIR PUMP
STRAINER
1-1/4"
1-1/4"
1-1/2"
CLOROX FEEDER ASSY
CARTRIDGE FILTER

Figure 12. Recycle system with cartridge filter

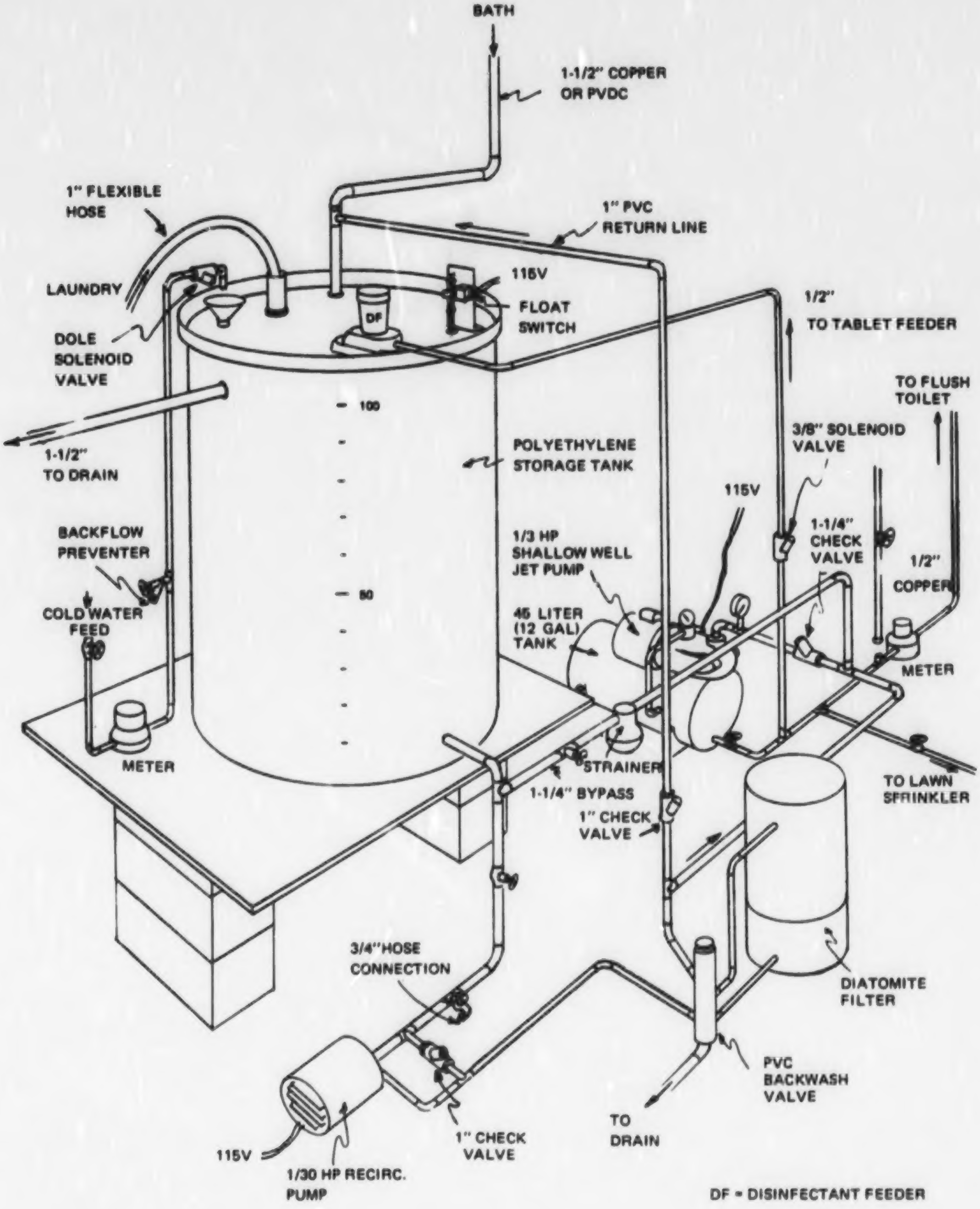
BATH
1-1/2" COPPER OR PVDC
1" FLEXIBLE HOSE
1" PVC RETURN LINE
LAUNDRY
115V
FLOAT SWITCH
DF
1/2" TO TABLET FEEDER
DOLE SOLENOID VALVE
100
TO FLUSH TOILET
1-1/2" TO DRAIN
POLYETHYLENE STORAGE TANK
3/8" SOLENOID VALVE
115V
BACKFLOW PREVENTER
1/3 HP SHALLOW WELL JET PUMP
1-1/4" CHECK VALVE
1/2" COPPER
50
COLD WATER FEED
45 LITER (12 GAL) TANK
METER
METER
STRAINER
TO LAWN SPRINKLER
1-1/4" BYPASS
1" CHECK VALVE
3/4" HOSE CONNECTION
DIATOMITE FILTER
PVC BACKWASH VALVE
TO DRAIN
115V
1" CHECK VALVE
1/30 HP RECIRC. PUMP
DF = DISINFECTANT FEEDER

Figure 13. Recycle system with diatomite filter

(shown in Figure 13) was somewhat more complicated because of the need for recirculation as explained below. Laundry and bath water were collected in a suitably sized vented storage tank, provided with an overflow pipe, side bottom outlet, and a low-level control system for supplemental feed water. The stored wash water was either continuously (see Figure 12) or intermittently (when the pressurization pump operated, see Figure 13) disinfected prior to filtration. The treated water was pressurized by a 1/3 HP shallow well jet pump mounted on either a 45 or 115 liter pressure tank, controlled by a pressure switch over the range of 105 to 210 cm Hg. When the pump was activated, wash water was pulled through a cartridge or diatomite filter and pressurized. This arrangement, with the filter upstream of the pump, had several advantages:

(1) The filtration system operated under a vacuum (0-65 cm Hg) while the pump was running, and only 4.5 to 11.5 cm Hg positive pressure at all other times. Hence, the system, up to the pump check valve, was under minimal pressure at all times, thereby minimizing leaks as well as filtration system design requirements.

(2) The pump was protected by the filter from any harmful debris.

A filter by-pass with an in-line strainer was also provided in case of filter breakdown.

In order to preclude contamination of an existing water supply, no cross-connections were allowed, and a suitable air gap was provided for the feed water inlet to the storage tank. For additional protection of the potable water system, an A.S.S.E. (American Society of Sanitary Engineers) approved double-check valve assembly (Watts No. 9 backflow preventer) was installed in the house service line. This device provides positive protection against back-syphonage and backflow if the supply pressure should ever fall below recycle system pressure at the same time that a cross-connection (pressure or gravity type) existed. Some localities may require the installation of a more sophisticated backflow prevention device such as a reduced pressure device (similar to the double-check valve assembly with an added differential pressure controlled relief valve). An additional requirement of the national plumbing code, not imposed on any of the test units installed, states that all non-potable water supplies must be color coded yellow. In general, plastic piping, fittings and valves were used for those lines not under a positive pressure greater than 35 cm Hg. All other lines consisted of copper tubing and bronze fittings. The acceptance of plastic piping for uses other than cold water drain lines, varies from one locality to another, and appears to be gaining in favor in many areas. The design and installation of all recycle systems were subject to prior approval by local and state authorities in both Connecticut and Rhode Island.

Two local plumbing contractors were used to install the wash water recycle systems in the three test homes. The systems in homes #7 and #8 were installed by the same contractor (see Figures 14 and 15). The installations in homes #7 and #8 were completed in approximately 8 hours each. In home #7, about one-half of the time was spent plumbing the recycle system (cartridge filter), per se, with the remaining time (4 hours) spent on connection of the system to the house plumbing. In home #8, 5 hours was spent on recycle system (diatomite filter) interconnections, with only 3 hours required for house plumbing connections. In home #6, approximately 10 hours were required for system interconnection. This excessive installation time reflects the plumber's lack of experience with PVC piping and fittings. Four hours were spent on house plumbing connections.

In general, no impairment of flush toilet operation was observed in the three test homes due to the recycling of filtered, disinfected wash water. In two of the three homes, reduced flush operation was successfully employed. Continual chlorination of the stored wash water effectively inhibited bacterial growth, and no unpleasant odors were detected in any of the bathrooms during normal operation.

Stable chlorine residuals were maintained at the point of reuse, despite the presence of interfering agents (soaps, detergents). In general, the susceptibility of the more resistant enteric bacterial pathogens to free chlorine is essentially the same as that of the coliform bacteria,[8] which were readily controlled. Viruses are more resistant to chlorine than coliform bacteria, and a negative coliform test does not necessarily exclude viruses. However, within a home, the possibility of viruses (or other pathogenic organisms) being transmitted by toilet flushing reuse, although possible, is less likely than by normal means (physical contact, inhalation, or ingestion).

The clarity and color of the recycled water attained by the diatomite (swimming pool) filter proved to be satisfactory in terms of aesthetic acceptance by the homeowner and was

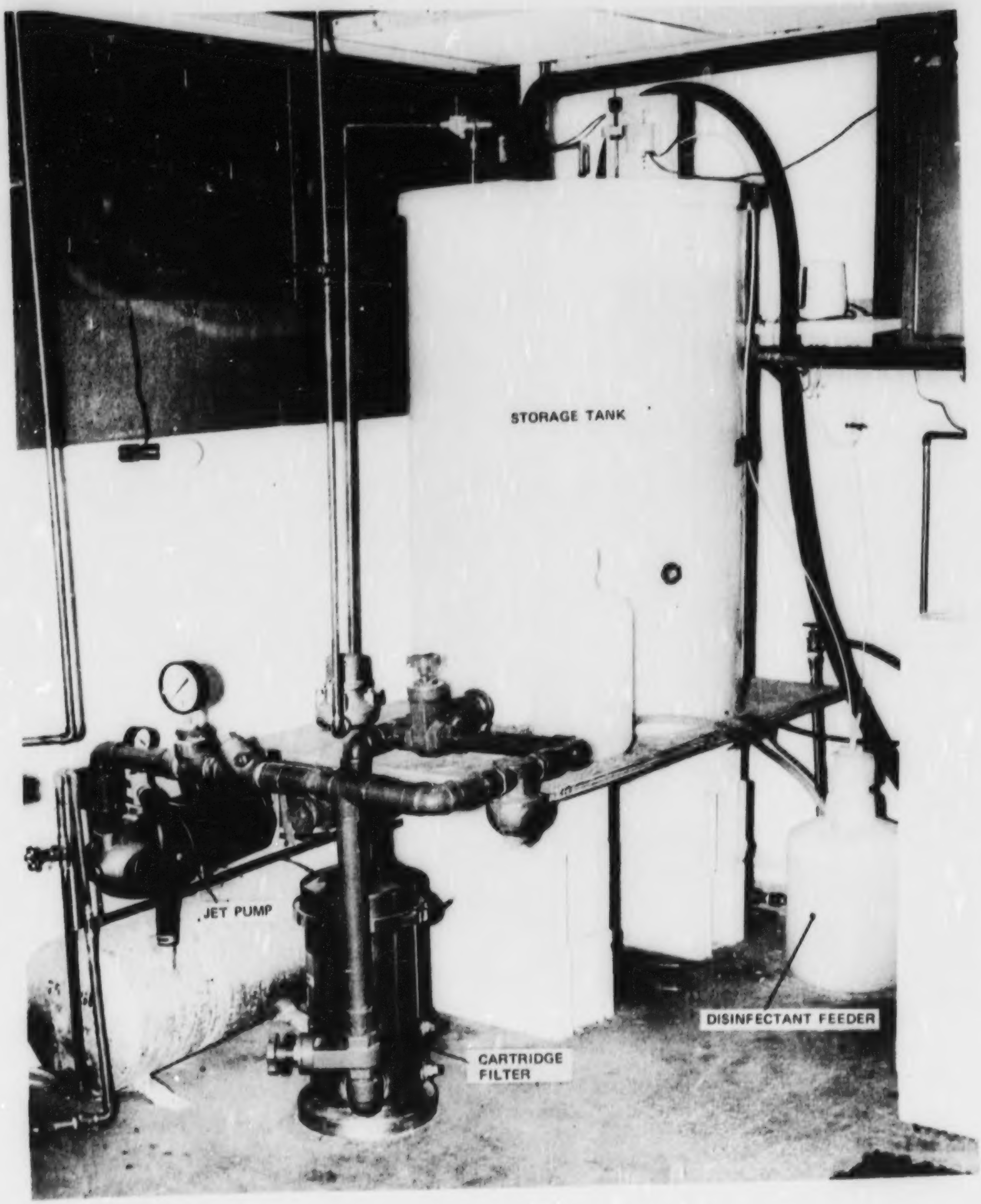
STORAGE TANK
JET PUMP
DISINFECTANT FEEDER
CARTRIDGE FILTER

Figure 14. Recycle system with cartridge filter: installed

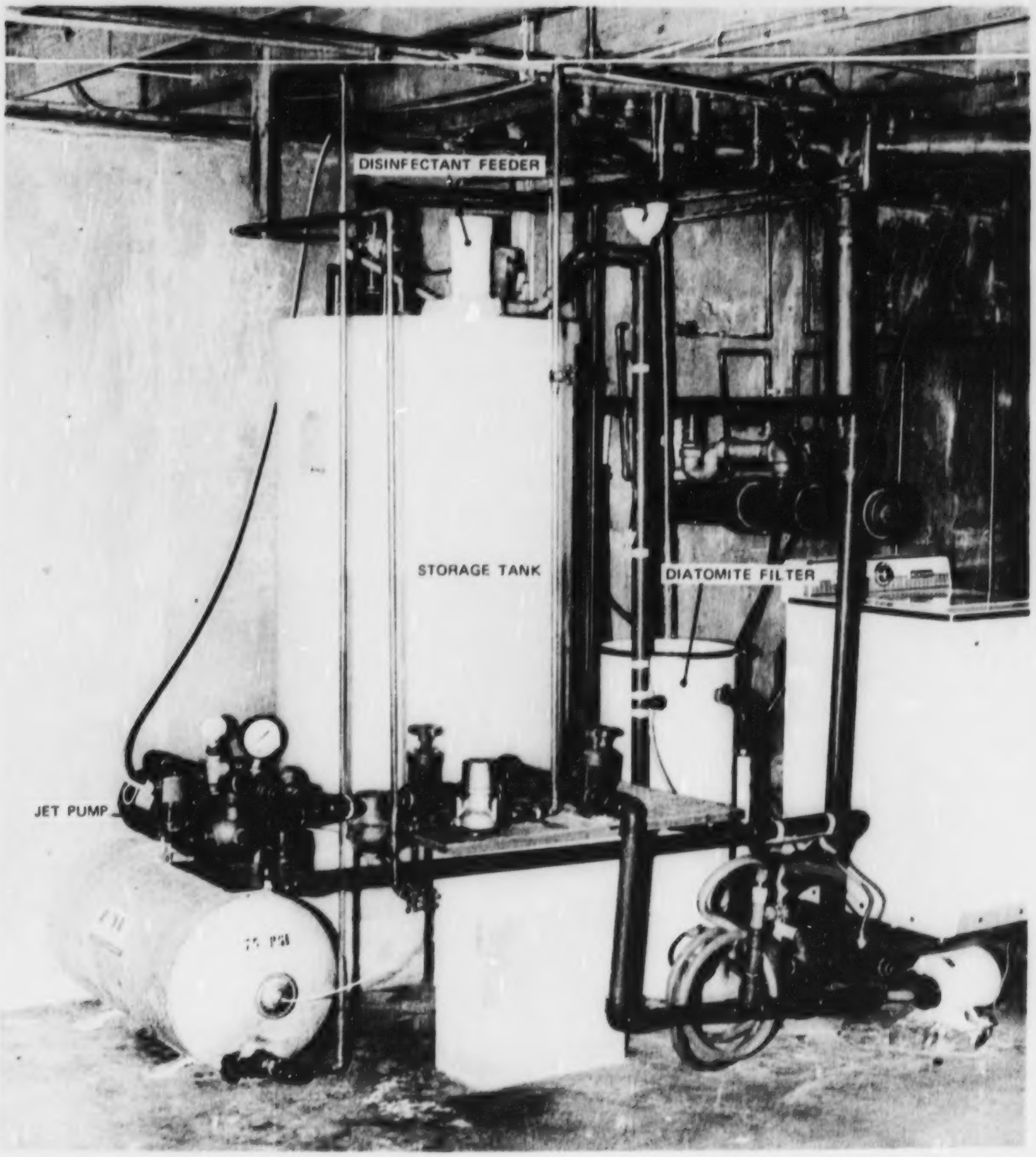
DISINFECTANT FEEDER
STORAGE TANK
DIATOMITE FILTER
JET PUMP
75 PSI

Figure 15. Recycle system with diatomite filter: installed

achieved with relatively low operating costs and maintenance requirements. The residual suspended solids in the recycled wash water did produce temporary stains in the toilet bowls which resulted in increased cleaning requirements. Since dissolved soaps and detergents were not removed by the diatomaceous earth, the foaming tendency of the wash water was not significantly reduced. However, no problems due to foaming were observed at the toilet inlet valve during refill of the water closet tank.

Lawn Watering Reuse

The original program plan called for the installation of two wash water recycle systems in San Diego, California, similar to those described above, to explore the feasibility of reducing lawn water consumption in a water short region. The normal water use patterns summarized previously show that lawn water consumption averaged 1340 and 1000 lpd respectively in homes #1 and #2 during the growing season. Based on full utilization of laundry and bath wastes, lawn usage could have been reduced by 455 lpd (34%) and 197 lpd (20%), respectively. Maximum utilization would probably have required a significant change in lawn watering habits by both homeowners in order to use the treated water as it became available.

Because of possible harmful effects of waste wash waters on the lawns, the reuse of laundry water was pre-tested during the preliminary monitoring period (Phase I). The principal concerns are with chemical effects on vegetation and soil chemical makeup. In general, soils that are acid, sandy and well-drained should provide the most favorable results. Homeowners #1 and #2 watered a small test plot with laundry water on a weekly basis and no short-term (3-4 months) adverse effects were noted.

Just prior to the scheduled installation, however, the San Diego Public Health Department failed to approve the experimental reuse of waste water on lawns. They were opposed, in principle, to any decentralized control of waste water management, and did not wish to encourage such a trend by setting a precedent in this case.

In order to accomplish the original program objectives, the reuse of wash water for lawn irrigation was subsequently incorporated into two of the toilet flushing recycle systems in the Southeastern Connecticut area (homes #6 and #7) primarily to supplement existing toilet flushing reuse and further reduce waste flow. This was done with the full cooperation of local public health officials even after being appraised of San Diego's objections.

In home #6, a 33 sq m test plot received average waterings of 100 lpd for three months and 400 lpd for another three-month period. In home #7, a 14 sq m test plot was watered an average of only 15 lpd. Revolving sprinklers were operated by shut-off valves located near the pressure tank outlet, for convenience as well as safety. No operational problems, such as clogging of the orifices, were encountered during the test period. The soil at both locations was tested and characterized as generally sandy and acidic. At home #6, where much larger amounts of wash water were reused for lawn sprinkling, the soil drainage was characterized as fair. The drainage at home #7 was generally poor. No significant effects, adverse or beneficial, were noted on lawn growth or appearance throughout the test period or during the next growing season. The sprinkled areas were not sheltered from the normal rainfall and were, in fact, exposed to record rainfalls throughout portions of the test period. Problems may have developed if drought conditions prevailed. It is unfortunate that the lawn sprinkling tests could not have been conducted in San Diego to obtain more conclusive information.

The effect of lawn sprinkling with filtered, disinfected wash water on various soil characteristics is shown in Table 18. The soil analyses were performed on samples taken at the end of the test period. Soil samples taken from the non-sprinkled area were assumed to be representative of soil conditions prior to the period of reuse. Although detergents are formulated of sodium salts of weak acids, the pH of the sprinkled wash water was found to be essentially neutral.

Excessive amounts of phosphate may tie-up iron, magnesium, calcium and other essential metals needed for plant growth. In both homes, low-phosphate detergents were used. The soil analyses indicate no significant decrease in the availability of the essential metals listed in Table 18. Spraying the lawns with wash water apparently effected small reductions in soil moisture content of from 10 to 20%. The moisture reductions may reflect an increased water repellancy, or may result from the normal differences in soil characteristics at the locations sampled. The effect of sodium buildup on soil permeability may become significant on a long-term basis. However, the lawn sprinkling tests were conducted on such a limited basis that sodium levels were not evaluated. Additional long-term testing of the lawn watering scheme would be required for a definitive evaluation of its effect on soil moisture.

Table 18. EFFECT OF LAWN SPRINKLING ON VARIOUS SOIL CHARACTERISTICS

Location		pH	Calcium	Potassium	Phosphate	% Moisture	Particle size distribution
#6	sprinkled	6.2	MH	M	VL	8.7	Fine - very fine sand
	non-sprinkled	6.6	MH	M	VL	9.6	
#7	sprinkled	5.3	VL	VL	M	11.4	Fine - coarse sand
	non-sprinkled	5.4	L	VL	M	13.9	

NOTES:

MH - Medium high
M - Medium
L - Low
VL - Very low

These level designations are relative to normal values found in the soils in this area and were assigned by the University of Connecticut Agronomy Testing Laboratory.

Reuse for lawn sprinkling may present a possible hazard because of the greater accessibility to the recycled wash water, should any pathogens be present. This hazard could be eliminated by a suitable underground discharge system.

Water Savings

Waste wash water (bath and laundry) was reused for toilet flushing and/or lawn sprinkling in homes #6, #7, and #8. Data for each specific type of reuse are shown in Table 19, for each of the three homes. In home #8, wash water was recycled exclusively for toilet flushing. In home #6, it became necessary to reconnect the water closet to the city water supply during the months of August and September in order to make changes in the filtration and pressurization system. During that period, wash water was reused exclusively for lawn watering through use of the filter by-pass line which incorporated a heavy duty Cuno cartridge filter.

The maximum amount of water savings attainable is equal to the water normally used for toilet flushing and/or lawn sprinkling. In actual operation the water savings will be diminished by an amount equal to the supplemental feed-

Table 19. WASH WATER RECYCLE SYSTEM: FLOW REDUCTION SUMMARY

Household and Phase I & III average inlet	Type of re-use	Net storage volume liters	Toilet lpd		Bath & laundry lpd		Lawn sprinkling lpd	Feed water lpd	Tank overflow lpd	Average flow reduction[b]		
			Phases I & III	Phase II	Phases I & III	Phase II				lpd	lpcd	% red.
#6 1900 lpd	toilet flush.	455	488	266	662	750	---	15.5	500	432	43.7	23
	toilet & lawn	455	448	337	662	794	106	44.5	396	510	51.5	27
	lawn sprink.	455	448	---	662	732	402	22.4	352	380[a]	38.4[a]	20[a]
#7 715 lpd	toilet flush.	305	210	193	282	265	---	10.6	83	189	37.8	26
	toilet & lawn	305	210	204	282	334	15.5	4.9	119	220	44.0	31
#8 735 lpd	toilet flush.	322	286	194	195	262	---	18.2	86	268 (176)	65.4 (42.9)	36[c] (24)
								Overall average[c]		305	44.0	26

[a] Not included in overall average, atypical reuse system.

[b] Note on calculation procedure - Homes #6, 7 and 8 had reduced flow toilets and showers during Phases II but not during Phases I and III. To put the data on the same bases with no reduced flow fixtures during all phases, the following was done:

- Effects of reduced flow showers were neglected.
- The flow reduction possible was assumed to be the average water used for toilet flushing during Phases I and III, plus any lawn watering in Phase II, minus the average feed water required in Phase II. The feed water requirement could be higher but the effect is probably small unless there is insufficient bath and laundry water to provide for conventional toilet flushing. See note c below regarding home #8.

[c] For home #8, the bath and laundry water is not sufficient to provide for flushing conventional toilets. In addition to the procedure outlined under note b, flow reduction was calculated by another procedure. The flow reduction possible was taken as the bath and laundry water available during Phase II minus the tank overflow. The flow reduction values resulting from this assumption are shown in parentheses. These values are thought more appropriate for home #8 and were used in calculating the overall averages.

water required due to both short-term and long-term imbalances in supply vs. demand. In homes #6 and #7, a comparison of wash water supply and water closet demand shows a substantial surplus of wash water available. In home #8, the supply deficit observed during the control period was converted into a surplus during the test period by the incorporation of dual-flush toilet devices, thereby substantially reducing water closet demand. In all three homes, the supplemental feedwater requirements averaged only 5% of the total water reuse requirements.

Average flow reductions (water savings) are also presented in Table 19. The overall average water savings for toilet flushing and/or lawn sprinkling was 305 lpd. The average savings for toilet flushing reuse only was 266 lpd. The incorporation of lawn sprinkling as a supplemental reuse mode in homes #6 and #7 increased the water savings by 16% to 18%. Greater flow reductions could be achieved by converting lawn sprinkling from a manual to an automatic operation through the inclusion of a high-level control system similar to the low-level control system previously described. The overall average flow reduction, on a per capita basis, was 44.0 lpcd. The average percentage reduction in total water consumption for all three recycle systems was 26%.

Additional Benefits

The reuse of waste wash water for toilet flushing and/or lawn sprinkling provided tangible benefits to two of the three homeowners above and beyond the savings in water consumption. The recycle system, by minimizing the surges in outflow to the septic system associated with laundry and bath discharges, as well as by reducing total waste flow, allowed the septic tank and soil absorption system to operate more effectively.

In both homes #7 and #8, the septic systems performed poorly prior to recycle system installation. In home #7, the normal annual septic backup and associated odors were noticeably absent despite record rainfalls during the year. Inspection of the septic system at the end of the test period indicated all lines were clear with no sign of clogging or backup. In home #8, before and after installation of the recycle system, the household experienced difficulty laundering multiple washes (in succession) without causing the septic system to back-up and overflow the standpipes. As a result, frequent trips to a commercial laundromat were necessary. This difficulty was not experienced during the test program.

SUB-SYSTEM DEVELOPMENT AND PERFORMANCE

Storage System

On the basis of criteria such as corrosion resistance, adaptability and ease of handling, and cost per unit volume, Nalgene heavy-duty conventional polyethylene tanks were selected. These plastic storage tanks are also translucent, thereby enabling water levels inside the tank to be monitored by the homeowner. Selection of tank capacity was limited by considerations of space and cost. Based on daily monitoring of the magnitude of both flush toilet and bath/laundry usage, as well as their relative balance or imbalance, 380 liter (100 gallon) tanks were deemed adequate for homes #7 and #8, and a 570 liter (150 gallon) tank was selected for home #6. Standard 455 liter galvanized pneumatic tanks were too difficult and costly to adapt, and custom-made galvanized tanks were more costly and difficult to handle than those selected. Two-hundred and eight liter (55 gallon) steel drums with polyethylene liners were economically attractive but were not considered the most convenient for the first prototype test units.

A sketch of a 380 liter polyethylene storage tank, with required modifications, is shown in Figure 16. The vented tank was provided with a 3.2 cm (1-1/4") side bottom outlet bulkhead fitting of PVC. A side bottom outlet was selected, as opposed to a bottom drain, to explore the benefits of using the storage system as a settling tank. 2.5 cm (1") and 3.8 cm (1-1/2") PVC bulkhead fittings were installed in the 0.95 cm LPE (linear polyethylene) cover to accommodate the laundry and bath wastes, respectively. A 3.8 cm overflow fitting was located approximately 12.5 cm below the cover. Design calculations indicated that a 9.2 cm allowance would have been sufficient to provide for a continuous inflow of 115 lpm. The tank rested on a sheet of 2.5 cm plywood and was elevated with concrete blocks to allow the overflow to gravity drain into the building main drain to the main septic tank. A check valve was incorporated into the overflow line to preclude backup of the septic system into the storage tank.

The storage tank was also provided with a low-level control system (LLCS) in order to ensure an adequate water supply at all times. The LLCS consisted of a solenoid controlled feed line valve activated by a sump pump type float switch installed as shown in Figure 17. A specially designed float rod assembly was fabricated for this application (see Figure 18). The LLCS was designed so that the feedwater line would be activated with the water level approximately 7.6

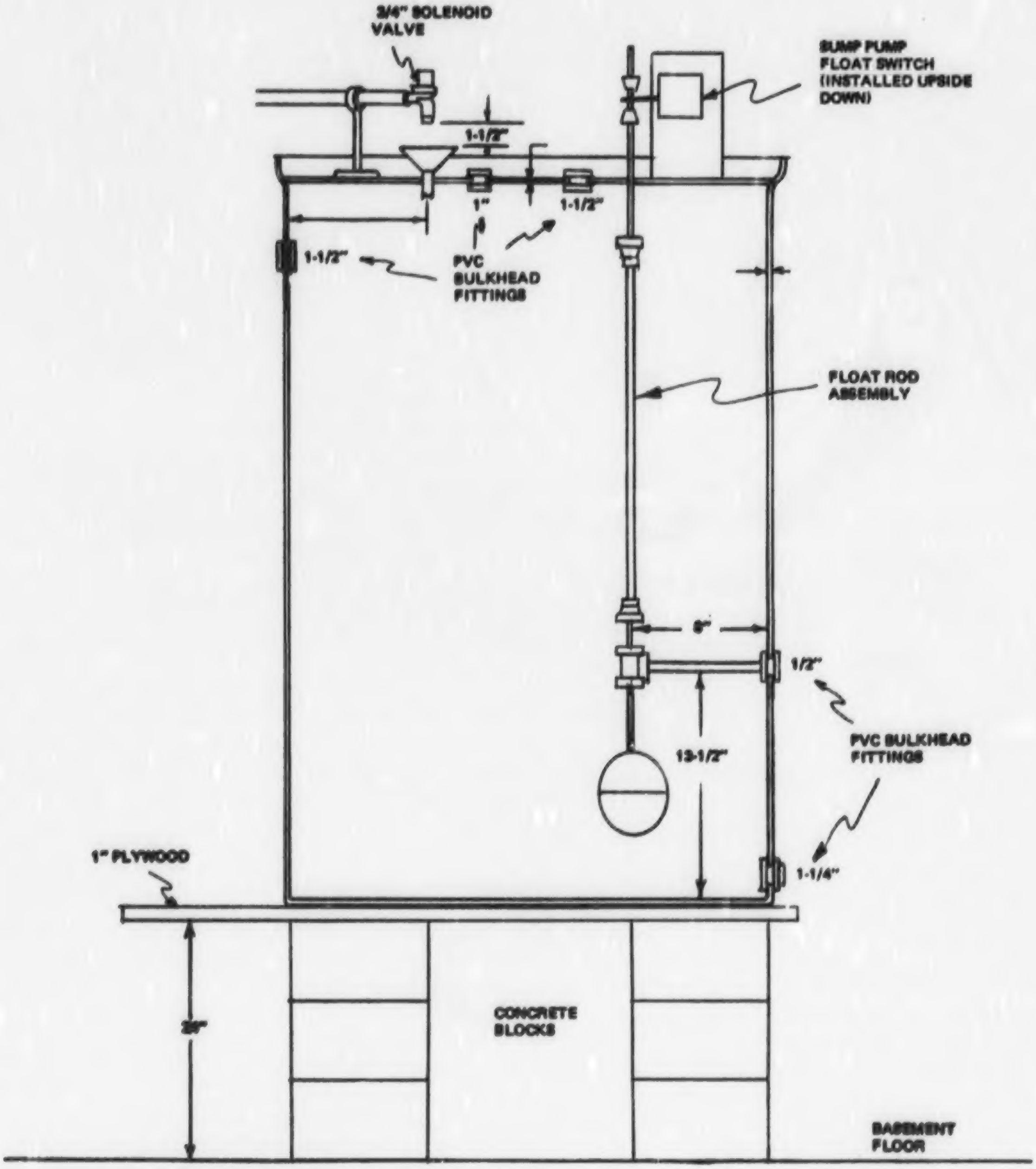
3/4" SOLENOID VALVE
SUMP PUMP FLOAT SWITCH (INSTALLED UPSIDE DOWN)
1-1/2"
1"
1-1/2"
1-1/2"
PVC BULKHEAD FITTINGS
FLOAT ROD ASSEMBLY
8"
1/2"
13-1/2"
PVC BULKHEAD FITTINGS
1" PLYWOOD
1-1/4"
26"
CONCRETE BLOCKS
BASEMENT FLOOR

Figure 16. Polyethylene storage tank

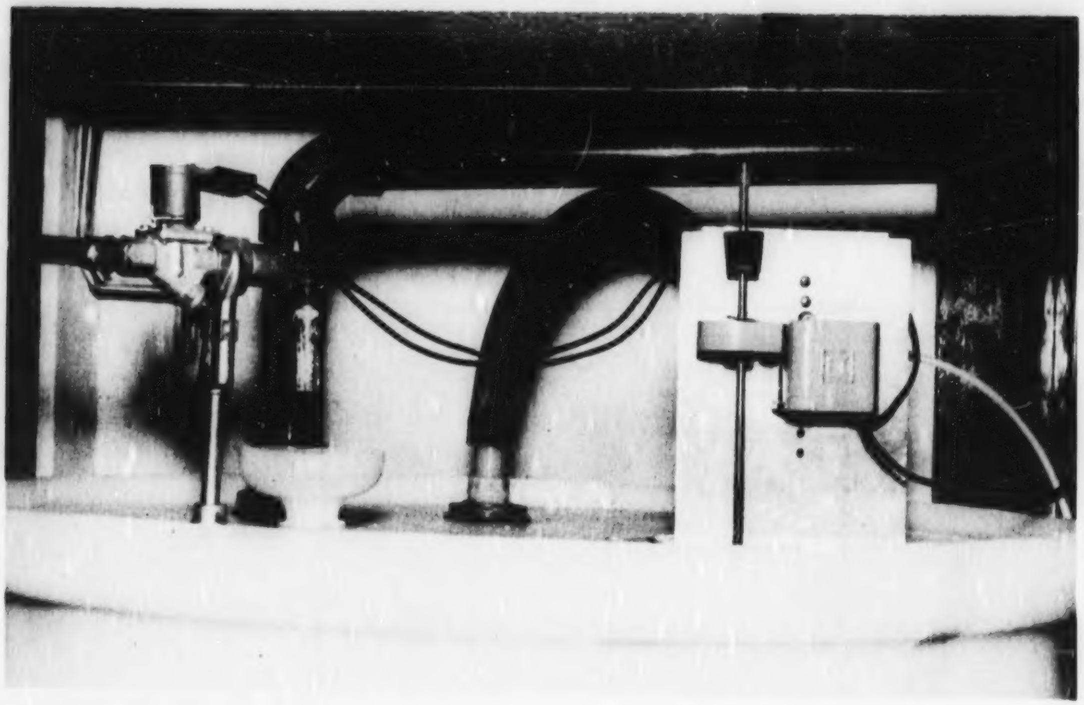

Figure 17. Low-level control system

cm above the top of the outlet pipe. This is a point where sufficient water is still available to handle 3 to 4 simultaneous toilet flushes. De-activation of feedwater supply occurred with the water level at 12.7 cm above the top of the outlet pipe. The effective wash water storage capacity of the tank was thus decreased by 28 to 47 liters.

The size of the storage tanks proved to be adequate in terms of collection capacity required prior to reuse as evidenced by the relatively small quantities of fresh feedwater required. The low-level control system performed reliably and maintained an ample supply of water in the tank at all times for toilet flushing and/or lawn sprinkling reuse. In homes #6 and #7, the tank overflow was capable of handling simultaneous bath and laundry inputs with the water level remaining well below the top of the tank. In home #8, the overflow initially did not function properly due to a partially clogged septic system and improper installation (insufficient slope from tank to soil pipe location). Subsequent cleaning of the septic system and increasing the pitch of the overflow line allowed for satisfactory overflow operation for the remainder of the test period.

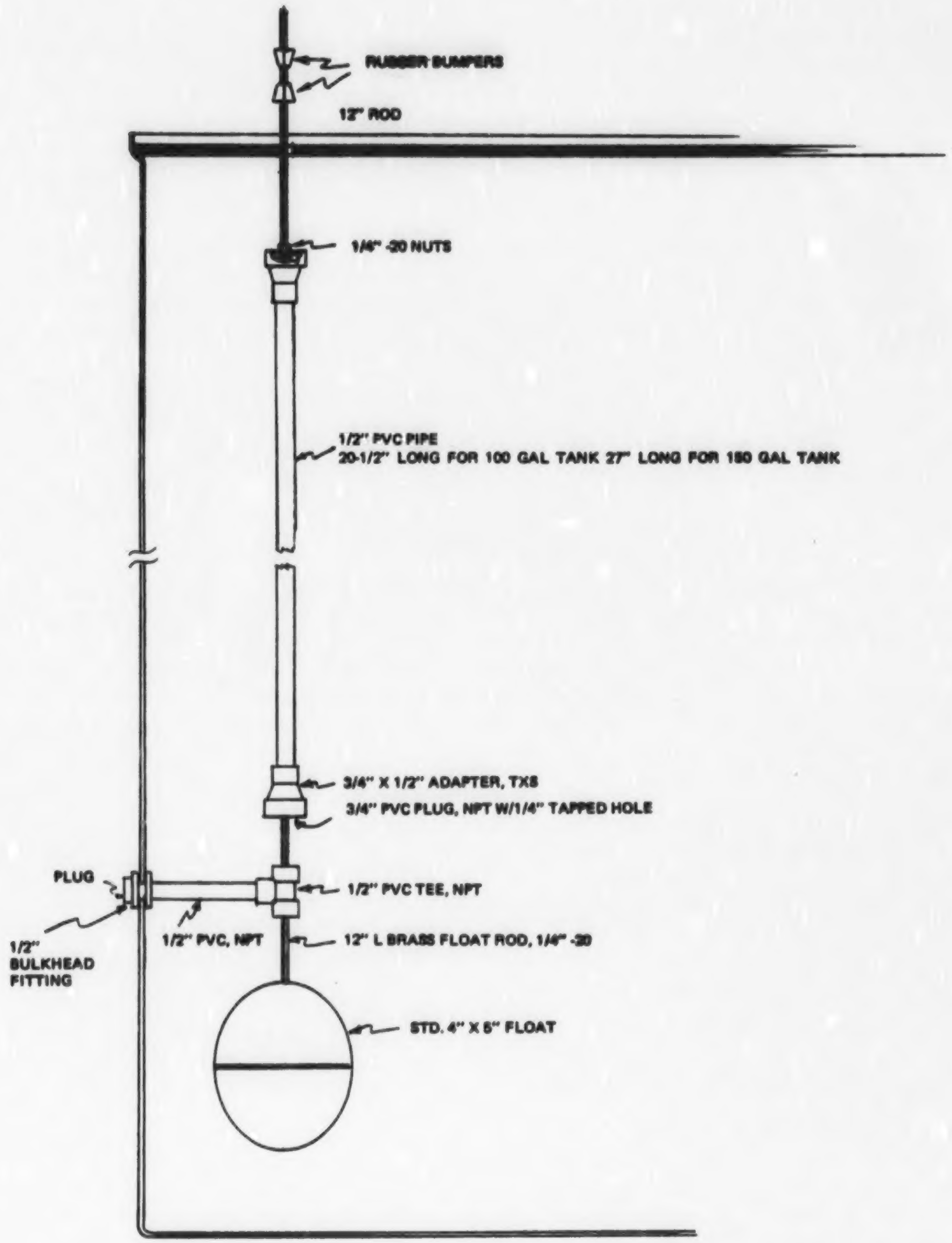
RUBBER BUMPERS
12" ROD
1/4" -20 NUTS
1/2" PVC PIPE
20-1/2" LONG FOR 100 GAL TANK 27" LONG FOR 150 GAL TANK
3/4" X 1/2" ADAPTER, TXS
3/4" PVC PLUG, NPT W/1/4" TAPPED HOLE
PLUG
1/2" PVC TEE, NPT
1/2" BULKHEAD FITTING
1/2" PVC, NPT
12" L BRASS FLOAT ROD, 1/4" -20
STD. 4" X 5" FLOAT

Figure 18. Low-level control float rod assembly

The side-bottom outlet permitted a substantial fraction of the suspended solids to settle out and accumulate at the bottom of the tank over a period of time. The obvious advantage of using the storage container as a settling tank is the decreased load on the filter and associated reduction in filter operating costs, particularly for the cartridge filters. The accumulated sludge has to be drained or pumped out periodically in order to maintain this advantage. An alternate design, more suitable for use with a diatomite filtration system, is to provide for bottom discharge, allowing virtually complete drainage and precluding any significant sludge build-up. A tank with a conically-shaped bottom (commercially available in heavy-duty polyethylene) would be ideal for this design modification. A polyurethane support could be molded at nominal cost. Without sludge separation by settling, the load on the filter would be increased and backwashing and precoating would probably be required at least twice as often. However, the increased filtration costs should be offset by reduced disinfection requirements.

Leaks developed at the tank outlet location in both homes #7 and #8. In both cases, threaded plastic (PVC) fittings were cracked by the application of excessive torque to a mating metal reducing bushing or adapter during installation. The connections were subsequently made up using all PVC fittings and no further leaks were observed.

Filtration System

The two primary reasons for the incorporation of a filtration system into the wash water recycle system are:

(1) To remove debris such as large dirt particles and lint that might adversely affect operation of the pressurization system or toilet control valves.

(2) To provide an effluent of sufficient clarity (as indicated by turbidity and suspended solids levels) to be generally acceptable to the user.

The first function can be readily accomplished by a simple basket-type strainer. The second function obviously requires a more sophisticated and costly filter. The criteria of aesthetic acceptability is a highly subjective and variable one, and may be amenable to public conditioning and education. The toilet flushing water standards suggested in Reference 1 were used as tentative guidelines and included a recommended maximum turbidity level of 20 turbidity units.

In the search for an optimum filtration system, the desired degree of filtration must be tempered by considerations of economic feasibility and convenience to the homeowner. In general, the finer the filtration, the more costly the operation. After a survey of available filter types, and discussions with various manufacturers, two alternate approaches were selected for evaluation. Cartridge filters were incorporated into the recycle systems of home #6 (8 months) and home #7 (12 months). Diatomite filters were installed in home #8 (12 months) and home #6 (3 months). The performance of each filter was continually monitored and evaluated in terms of effluent clarity (turbidity), suspended solids levels and filter capacity. In addition, the homeowner recorded, as shown in Figure 19, such data as filter pressure drop, storage tank level, and quantity of disinfectant used. Information relating to both routine maintenance and operational problems was also noted. Turbidity and suspended solids analyses were performed in accordance with the standard methods recommended in Reference 9.

Diatomite Filter

The specific unit selected was a Diaclear LP-18 diatomite filter, and is shown in Figure 20 with the pagoda-shaped filter septum removed. The septum is fabricated from woven polypropylene and has a filtering surface area of 1.67 sq m. In order to facilitate backwashing, the filter was modified by incorporation of a PVC reciprocating slide valve as illustrated in Figure 21. Prior to filter operation, the filter is pre-coated by circulating a pre-mixed slurry containing approximately 0.7 kg of diatomite through the filter, the slurry being educted through a separate valve controlled feed port (see Figure 21). The average time required for pre-coating the filter was approximately 5 minutes. The pre-coat procedure was performed in accordance with the manufacturer's recommendations and follow-up consultations, and was considered optimum for this application. Changing the position of the slide valve reverses the flow through the filter and allows the dirty filter cake to be backwashed out to the drain with the use of 75 to 95 liters of filtered wash water. Fresh water for backwashing can be fed in through the same connection as used for pre-coating. This particular filter model was selected because of the relative ease with which it can be backwashed. Sand filters were not considered because of the large flow rates (75-115 lpm) normally required for back-

HOME NO.____/PHASE II

DATE									
TIME									
METER READINGS, GALLONS	WATER CLOSET								
	BATH	COLD							
		HOT							
	LAUNDRY	COLD							
		HOT							
	FEED WATER								
	INLET								
FILTER ΔP, INCHES HG									
FILTER RENEWAL	BACKWASH VOL, GAL								
	TIME REQ'D, MIN.								
STORAGE LEVEL									
SAMPLE NUMBER	STORAGE TANK								
	TOILET TANK								
NUMBER OF OCCUPANTS									

COMMENTS:

Figure 19. Typical data collection form - recycle system

washing of systems that would be suitable in size for home use.

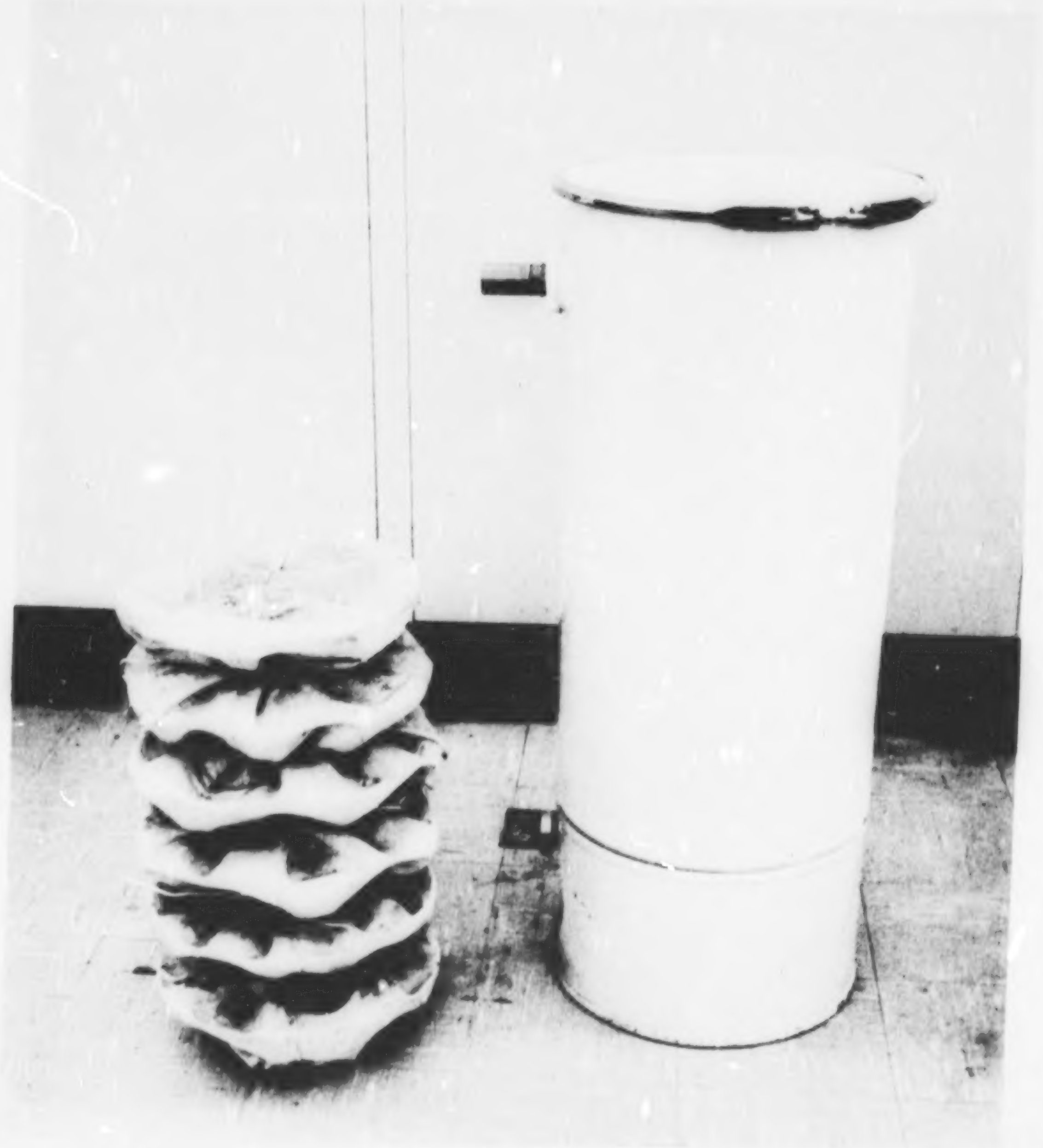

Figure 20. Diaclear diatomite filter

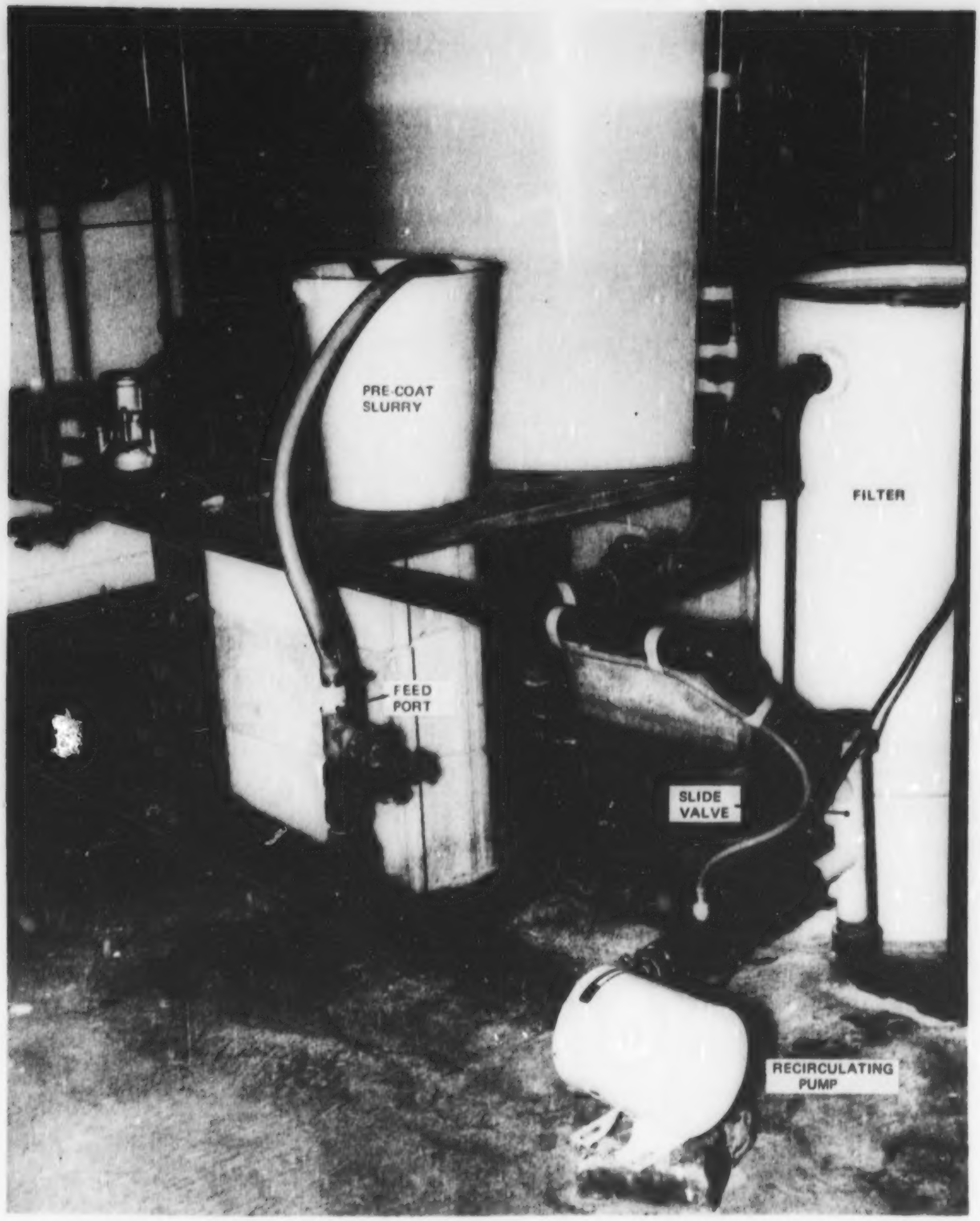
PRE-COAT SLURRY
FILTER
FEED PORT
SLIDE VALVE
RECIRCULATING PUMP

Figure 21. Diatomite filtration system: installed

Preliminary testing of this filter unit without the normal recirculation gave poor results. In the absence of flow, the filter cake rests at the bottom of the filter. Each time the jet pump is activated, the filter cake is reapplied to the system, but sufficient time apparently elapses to permit a significant portion of the wash water to pass through unfiltered. Normal recirculation rates are in the order of 40-80 lpm/sq m filter area. In this application, recirculation levels of this magnitude would be impractical in terms of operating costs and noise levels. Hence, a compromise solution was sought, and a 1/30 HP recirculation pump was incorporated which did provide acceptable effluent clarity after several hours of recirculation. The recirculation pump required a by-pass line and check valve in order to preclude cavitation during pressurization of the filtered wash water.

A diatomite filter was first evaluated in home #8, with the filtered wash water reused exclusively for toilet flushing. Sears standard swimming pool grade diatomaceous earth was utilized in all but one instance. For the third filtration cycle, a much finer grade (Johns-Mansville supercel) was used for a comparative evaluation. Table 20 summarizes the filter performance data for homes #8 and #6. The volume of wash water processed and number of days is tabulated for each filtration cycle. Backwashing was performed when the filter pressure drop, as indicated by the pump vacuum gage, exceeded 64 cm Hg. The typical variation of filter pressure drop with time observed for this type of filter is shown in Figure 22. After the first few days of operation, a plateau of ~ 40 cm is reached and maintained until the last few days of the cycle. The dropping and re-application of the filter cake by temporary shutdown of the recirculation pump can result in a temporary lowering of the pressure drop with a concomitant extension of filter life.

In home #8, the filter was backwashed prematurely during the 2nd, 3rd, 5th, and 6th cycles. The 2nd and 5th cycles were prematurely terminated to accommodate replacement of the recirculating pump. The first recirculating pump developed excessive noise which was later traced to a defective stator winding. The second pump developed a leak at the shaft seal due to the corrosive effect of excessive chlorine residuals discussed in a later paragraph. A sealless magnetic drive 1/30 HP pump was used for the remainder of Phase II. No further problems were encountered. The 3rd cycle was terminated as a result of the poor performance being obtained with the supercel grade of diatomaceous earth and the 6th cycle due to a penetration of the filter septum. The wire form on which the filter septum is positioned snapped at a welded joint (which was probably weakened by overchlorination during initial testing) and subsequently penetrated the polypropylene bag. Some corrosion of the interior surfaces of the filter housing was also noted in home #8. A change in materials of construction for both the wire form and filter housing from galvanized to stainless steel or a suitable plastic is apparently indicated for this application

Table 20. DIATOMITE FILTRATION SYSTEM - PERFORMANCE DATA

HOME #8

Time Period	Length of Period (days)	Diatomite pre-coat Grade	Wt., Kg	Volume of wash water processed, liters/cyc.	Turbidity levels, ppm Storage	Toilet	Suspended solids, mg/l Storage	Toilet
1	124	std	0.68	23,700	14-30	13-30	12-21	15-25
2	50[a]	std	0.68	11,700	19-29	25	23-32	29
3	16[a]	Super-cel	0.68	3,350	40-60	20-60	--	--
4	56	std	0.68	14,500	18-40	--	23-45	--
5	16[a]	std	0.82	2,690	40	25	66	36
6	7[a]	std	0.82	1,100	110	90	--	--
7	83	std	0.82	15,500	15-39	15-29	10-38	--

HOME #6

Time Period	Length of Period (days)	Diatomate pre-coat Grade	Wt., Kg	Volume of wash water processed, liters/cyc.	Turbidity levels, ppm Storage	wc/lawn	Suspended solids, mg/l Storage	wc/lawn
1	49	std	0.82	12,800[b]	23	19	12	20
2	57	std	0.82	14,000[c]	22	20	15	19

[a] Backwashed prematurely for reasons other than excessive filter pressure drop (see text).

[b] Reused primarily for lawn sprinkling.

[c] Reused primarily for toilet flushing.

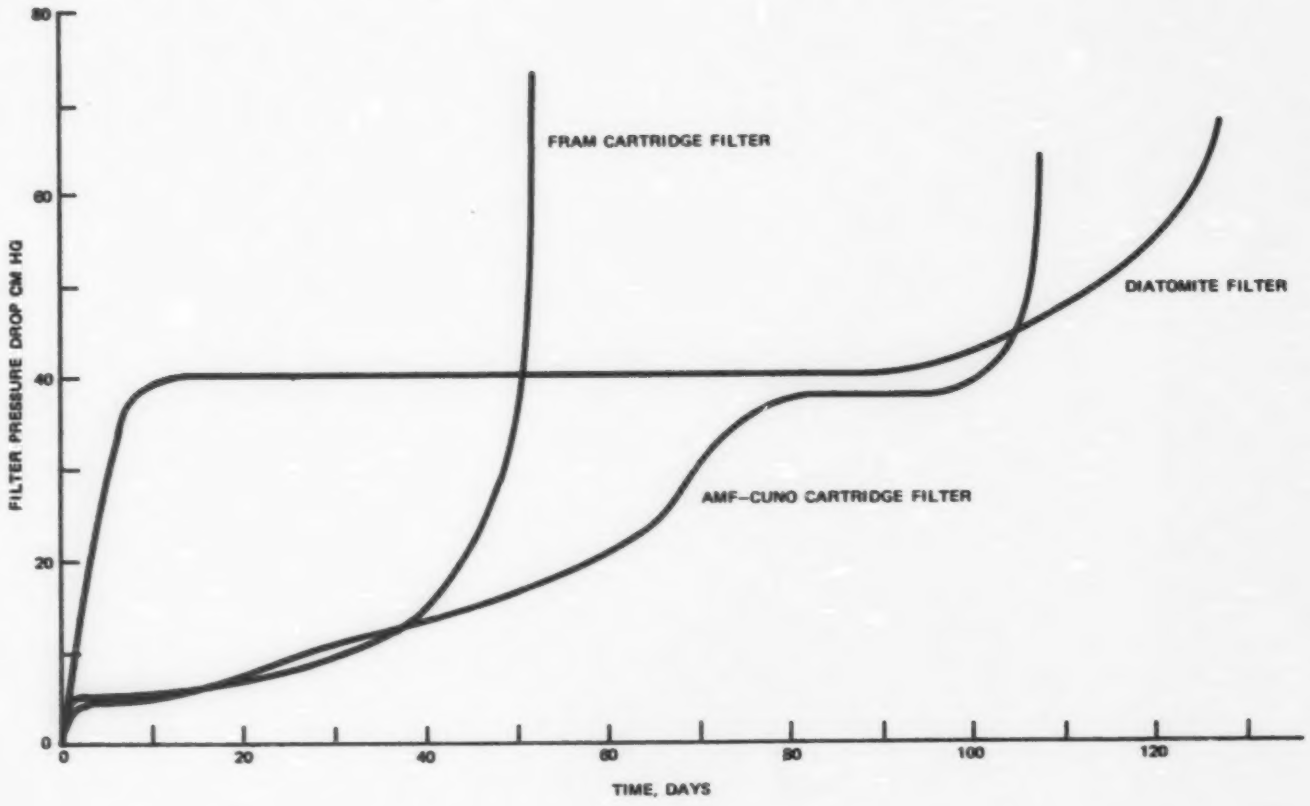

Figure 22. Filter pressure drop vs time

Three complete filtration cycles were obtained during Phase II. The volume of wash water processed per cycle ranged from 14,500 liters to 23,700 liters, with a corresponding cycle life of from 56 to 124 days. The observed spread in the data probably reflects the effect of sludge build-up at the bottom of the storage tank. The sludge was pumped out of the tank at the end of period #5 by simultaneous stirring and dilution with supplemental feed water. The implications for storage tank redesign were discussed in a previous paragraph.

In home #6, two full filtration cycles were obtained. The filter capacity ranged from 12,800 to 14,000 liters of wash water, with corresponding cycle lives of from 49 to 57 days. The relatively short cycle life, as compared with home #8, is a consequence of the much greater daily water consumption in home #6.

Turbidity and suspended solids levels were determined at both the storage tank and water closet locations. In general, the filtered wash water had a slight greyish cast as compared with tap water. At the lower turbidity levels the color was scarcely noticeable. During normal operation, the turbidity of the water recycled to the water closet ranged from 13 to 30 ppm in home #8, and 19-20 ppm in home #6. Suspended solids levels ranged from 15-25 mg/l in home #8 and 19-20 mg/l in home #6. The 5th and 6th filtration cycles in home #8 were not included with the data summarized above due to the developing loss of integrity of the filter septum. The variation in the turbidity and suspended solids data reflects, to some extent, the time interval between sampling and the most recent bath and/or laundry input, as well as influent turbidity and suspended solids levels. Although the effluent turbidity levels ranged somewhat higher than the proposed design criteria, they were found to be aesthetically acceptable.

COD (chemical oxygen demand) levels for the filtered, disinfected wash water were also determined and ranged from 53 to 85 mg/l.

Cartridge Filters

As an alternate approach, two different cartridge-type filters were evaluated during the test program. Since no circulation was required, the systems incorporating these filters were inherently less complicated. One of the cartridge filters selected was an AMF/Cuno CG 4DC-1 stainless steel filter shown disassembled in Figure 23. Four cartridges surround the internal centerpost. The model was selected primarily on the basis of ease of maintenance,

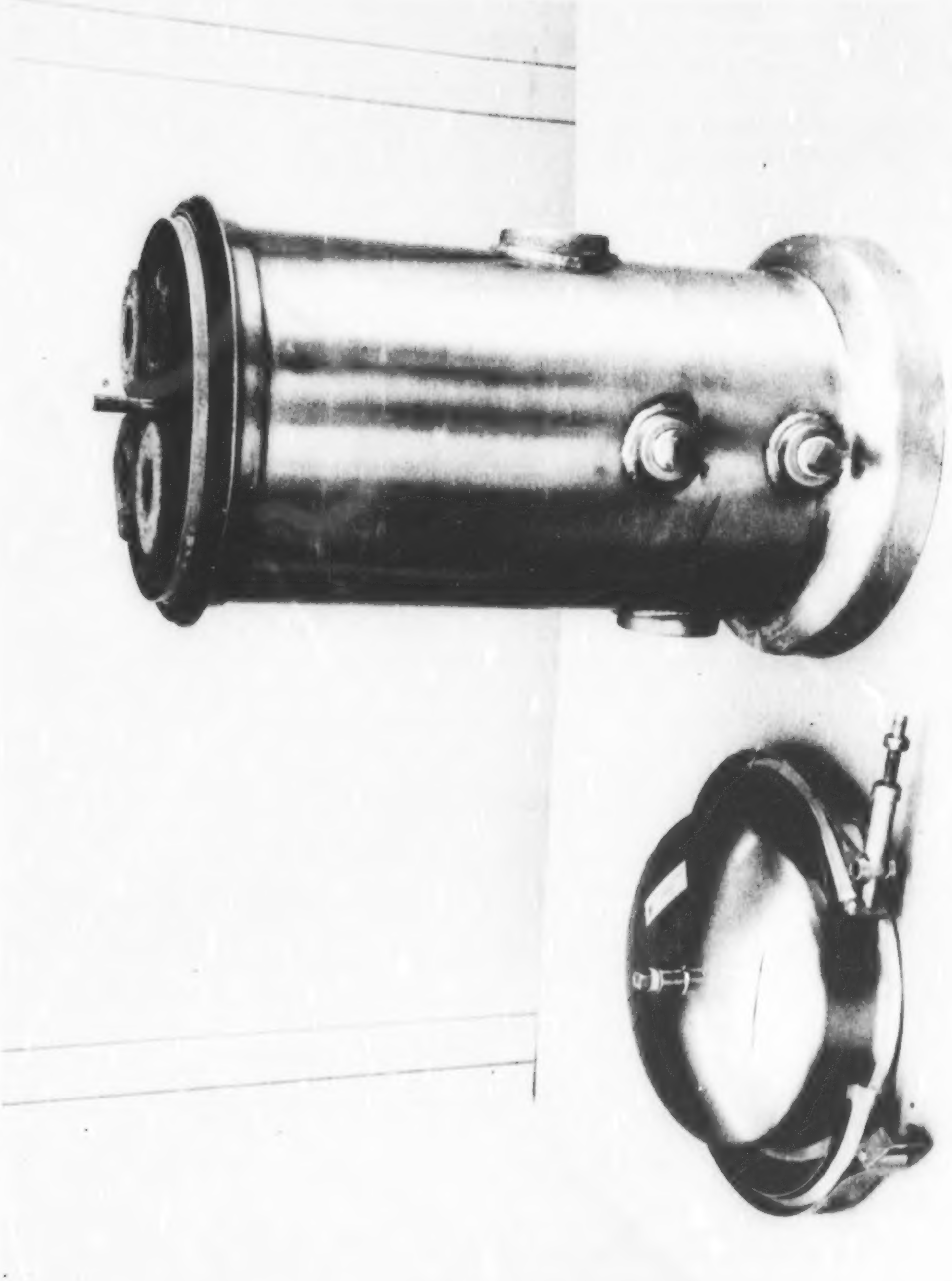

Figure 23. AMF/CUNO cartridge filter

availability, corrosion resistance, and the relatively large number of cartridge types and porosities available. Microklean depth-type, disposable cartridges (wool fiber, phenolic resin) with nominal solids removal down to 5 to 25 microns, and Cuno-Cel surface type disposable cartridges (pleated cellulose) with a nominal solids removal down to 10 microns were chosen for testing.

A Fram MCM epoxy-coated steel filter shown in Figure 24 was the other unit tested. This model was selected primarily on the basis of its low initial cost. The filter is designed to accept a single large cartridge of the surface type (pleated cellulose), with nominal solids removal down to 5 to 15 microns or the depth type (glass fibers), with solids removal down to 10 microns. Both the Fram and AMF/Cuno filters were provided with vent and drain plugs.

Fram Filter -

A Fram MCM filter was tested in home #6, with an AMF/Cuno 1M filter installed in the by-pass line. Cartridges were replaced when the filter pressure drop exceeded 64 cm Hg. The typical variation of filter pressure drop with time is illustrated in Figure 22. The pressure drop is seen to increase very gradually and remains relatively low throughout most of the filtration cycle. Toward the end of the cycle, the rate of increase is substantially accelerated. Cartridge replacement was readily accomplished by the homeowner in approximately 10 minutes. Table 21 summarizes the filter performance data for home #6.

The volume of wash water processed by the surface-type cartridges progressively diminished from 15,650 liters to 5,200 liters, with a correspondingly shorter cartridge life. This apparent diminution in filter capacity was presumably due to the gradual build-up in and partial carryover of sludge at the bottom of the storage tank. The sludge carryover was apparently enhanced in periods 7, 8, and 9 by the supplemental reuse of wash water for lawn sprinkling. Hence, periods 1 and 5 would be indicative of filter cartridge capacity if the sludge were periodically removed every 3 to 4 months by draining or pump-out. Periods 7, 8, and 9 reflect conditions of filtration without the aid of a settling tank.

A single 10-micron depth-type cartridge was tested and became clogged after having processed only 3305 liters (10 days) of wash water. Due to a delay in the procurement of additional extended surface cartridges, the bypass filter was operated for a total period of 39 days.

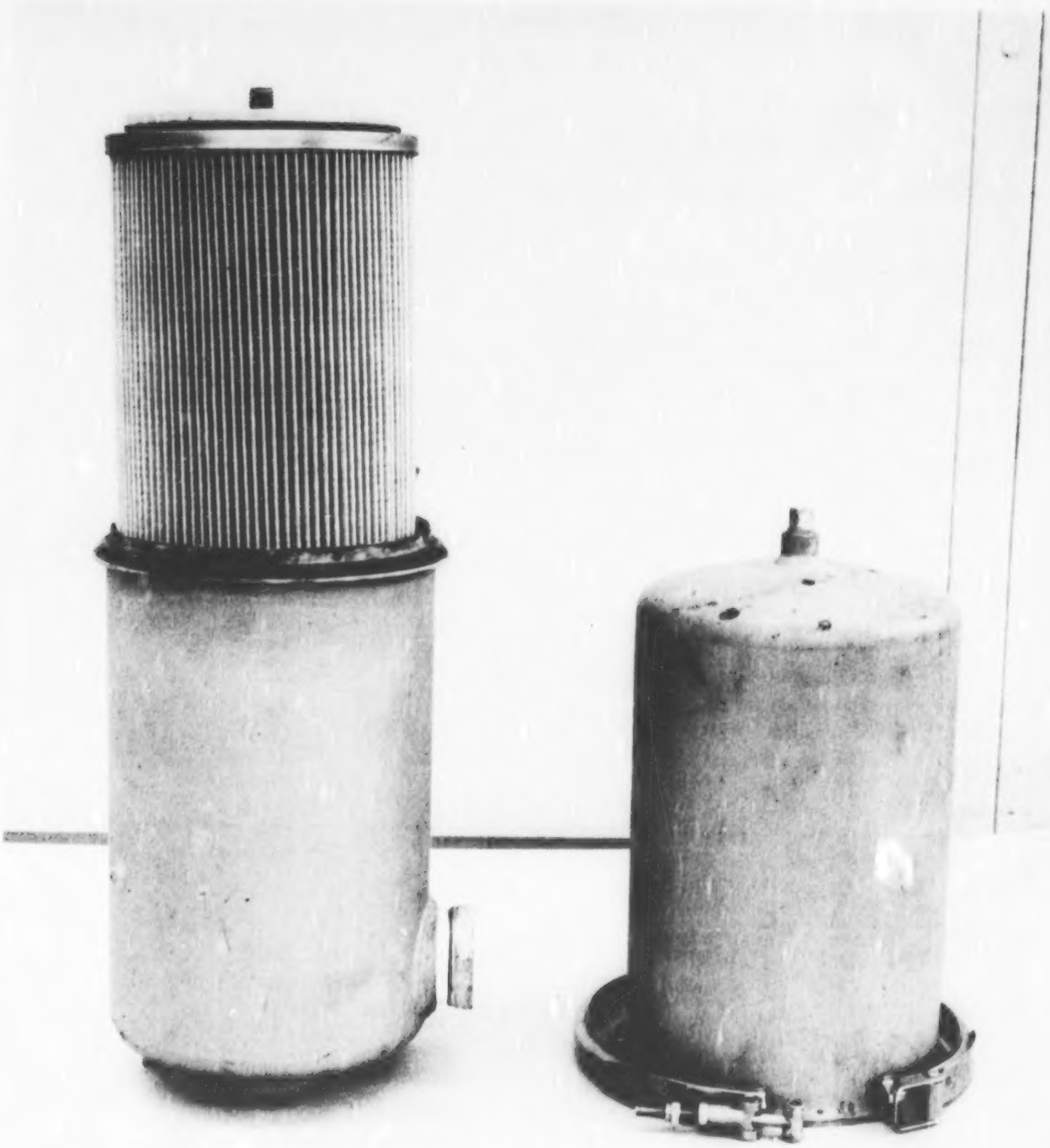

Figure 24. Fram MCM cartridge filter

Table 21. **FRAM** MCM CARTRIDGE FILTER/CUNO IN BY-PASS FILTER - PERFORMANCE DATA

Time period	Cartridge description	Cartridge life, days	Volume processed liters/cyc.	Turbidity levels, ppm		Suspended solids, mg/l	
				influent	effluent	influent	effluent
1	C-744, 5 micron, extended surface	52	15,650	70-90	40-55	49-67	26-36
2	C-729, 10 micron, depth type	10	3,305	90	50	64	29
3	Cuno by-pass, 10 micron depth	3	855	90	68	--	--
4	Cuno by-pass, 25 micron depth	11	3,100	85-90	78-85	68	60
5	Cuno by-pass, heavy-duty	25	6,200	85	82	66	64
6	C-744-15, 15 micron, extended surface	46	12,000	75	55	52	29
7	C-744-15, 15 micron extended surface	22	9,450	90	60	65	32
8	C-744-15, 15 micron, extended surface	12	5,150	85	60	--	--
9	C-744-15, 15 micron, extended surface	8	5,220	110	65	66	33

Depth-type cartridges with nominal ratings of 10 to 100 (heavy-duty) microns were used successively, and evidenced respective filter capacities of 855 to 6200 liters (3 to 25 days). Two Cuno 1M filters equipped with heavy-duty cartridges should be equivalent to the Fram MCM filter in terms of filter cartridge life.

Effluent turbidity levels for C-744 (extended surface) cartridges ranged from 40 to 65 ppm, representing turbidity reductions of from 27 to 50%. Filtrate suspended solids levels ranged from 26 to 36 mg/l, corresponding to percentage reductions of from 44 to 50%. The heavy-duty by-pass filter achieved negligible reductions in turbidity and suspended solids levels. As was the case with diatomite filtration, the filtrate had a slightly greyish cast.

AMF/Cuno filter -

A Cuno stainless steel cartridge filter received testing in home #7. Replacement of the filter cartridges was easily accomplished by the homeowner in approximately 10 minutes. Variation of filter pressure drop with time is shown in Figure 22.

Filter performance data for home #7 is summarized in Table 22. The capacity of the 10-micron depth-type (F2278-C1) cartridges progressively decreased from 11,000 liters (52 days) for period #3 to 4370 liters (18 days) for period #5 due to the sludge build-up and carry-over effect noted earlier. Based on a comparison of the average weight pick-up of the filter cartridges with the observed reduction in suspended solids levels, it is estimated that approximately 2/3 of the wash water suspended solids settled to the bottom of the storage tank during normal operation. The sludge was pumped out of the tank at the end of period #7. The performance of the last twc sets of cartridges, in terms of filter capacity, was markedly improved. In period #9, the improved G78 cartridges attained a filtration capacity of 22,450 liters (108 days), higher than any other cartridge tested. As anticipated, the 5-micron depth-type cartridges were able to process only one-half the amount filtered by comparable 10-micron cartridges. The 10-micron extended surface cartridges exhibited capacities intermediate between the original and improved depth-type cartridges.

Effluent turbidity levels for the 10-micron depth-type cartridges ranged from 30 to 95 units, equivalent to turbidity reductions of from 62 to 80%. Effluent suspended solids levels ranged from 34 to 68 mg/l, corresponding to reductions of from 63 to 71%.

The extended surface cartridges produced similar average effluent turbidity and suspended solids levels.

Filter Performance Comparison

Each filter system tested allowed for satisfactory toilet flushing and lawn sprinkling operation. The major performance differences between the filters were in the areas of filter capacity or life, and quality of the filtrate in terms of turbidity and suspended solids. Filtrate quality is essentially an aesthetic criteria involved in the promotion of homeowner acceptance. Filter capacity is important primarily because of its impact upon operating costs as well as homeowner maintenance requirements.

Table 22. AMF/CUNO CG4-DC1 CARTRIDGE FILTER PERFORMANCE DATA

Time period	Cartridge description	Cartridge life, days	Volume processed, liters/cyc	Turbidity levels, ppm		Suspended solids, mg/l	
				influent	effluent	influent	Effluent
1	F-2278-cl, 10 micron, depth-type	39[a]	4,950	220-280	135-140	--	--
2	F-2278-B3, 5 micron, depth-type	26	4,750	150	60	92-97	38-44
3	F-2278-cl, 10 micron, depth-type	52	11,000	175-280	40-70	110-193	36-68
4	F-2278-cl, 10 micron, depth-type	35	7,600	205-300	40-80	168-195	49-66
5	F-22878-F2, 25 micron, depth-type	18	4,370	190	95	135	92
6	38285-32, 10 micron, surface type	30	6,450	165-200	46-60	95-135	33-38
7	078-c-1, 10 micron, depth-type	34	7,400	170	65-95	--	--
8	38285-32, 10 micron, surface type	49	12,600	70-130	50-60	60-90	39
9	078-c-1, 10 micron,depth-type	108	22,450	90-160	30-65	93-158	34-51

[a] cartridges replaced prematurely for inspection.

Table 23 summarizes filter system performance for each of the three units tested. The diatomite filter achieved the best overall performance. The filter provided an average capacity of approximately 17,000 liters per cycle and a corresponding average backwashing interval of about three months. The average filtrate turbidity and suspended solids levels of 23 ppm and 21 mg/l, respectively, achieved by the diatomite filter, were judged to be quite satisfactory in terms of aesthetic acceptability. The two cartridge filters, roughly equivalent in performance, processed 74 to 88% as much wash water per cycle as did the diatomite filter, while permitting effluent suspended solids and turbidity levels approximately two to three times higher.

Table 23. **FILTER SYSTEM PERFORMANCE SUMMARY**

Filter system	Average volume processed, liters/cyc.	Equivalent filtration period, days	Average effluent turbidity levels, ppm	Average effluent suspended solids, mg/l	Annual operating costs, $/year
Diaclear LP-18 Diatomite	17,000	86	23	21	16
Fram MCM 15 micron surface-type	12,600	48	60	31	43
AMF/Cuno CG4-DC1 10 micron depth-type	15,000	71	62	43	40

Disinfection

It was anticipated at the start of the program that some provision for disinfection of the stored wash water would have to be made in order to control odors as well as to prevent health hazards. In order to establish disinfection requirements, several samples of non-disinfected wash water were collected one to two weeks after installation of two of the recycle systems, and were analyzed for coliform levels. The most probable number of total coliforms (MPN) ranged from <3 to 100/100 ml for home #8 and from 160 to 1000/100 ml for home #7. After four to five weeks holding, bacterial growth had increased by two to three orders of magnitude, and septic odors were detected. The data thus indicated that normally used amounts of both laundry detergents and bleach (Clorox) were clearly inadequate in terms of bacterial growth inhibition.

Based primarily on considerations of cost and disinfecting power, chlorination was selected as the best means of destroying pathogenic and odor-causing bacteria. The use of alkyl ammonium chlorides such as Roccal are not suitable for this application since they are neutralized by soaps and anionic detergents. A preliminary evaluation of the chlorine demand of untreated wash water samples was made for homes #7 and #8. Freshly collected wash water required chlorine concentration levels of ~ 5 mg/l to provide 1 hour chlorine residuals ≥ 0.5 ppm. Untreated wash water samples collected after one to two months of storage showed higher chlorine demand levels, ranging from 10 to 15 mg/l.

Two different techniques were utilized for disinfection of the stored wash water at the required dosage levels. Both represent a relatively simple and inexpensive means of chlorination. The first of these provides for the continuous introduction of diluted laundry bleach (NaOCl) with the use of an air lift feeder as illustrated in Figures 25 and 26. An alternate approach utilized an inexpensive chlorine tablet feeder designed for above ground pools (see Figure 27). Both calcium hypochlorite tablets and the more slowly dissolving chlorinated isocyanurates were evaluated in conjunction with this feeder. Both approaches are capable of providing pre-determined chlorine dosage levels based on average daily throughput rates. Specific dosage (concentration) levels at any given time may vary considerably, and will depend on such factors as (a) daily and weekly wash water supply and water closet demand profiles, (b) effective tank capacity, and (c) amount of dirt and sludge present in storage tank and filter at any time.

The performance of each feeder was periodically monitored, and samples were taken for analyses of chlorine residual, odor, and coliform count. Corresponding chlorine dosage levels were also determined. Chlorine residuals were determined by the Ortho-Tolidine method.[9] Testing for the coliform group was carried out by the multiple-tube fermentation technique, the results of which were expressed in terms of the Most Probable Number (MPN) per 100 ml.[9] Operation and performance details are given below for each of the methods of disinfection.

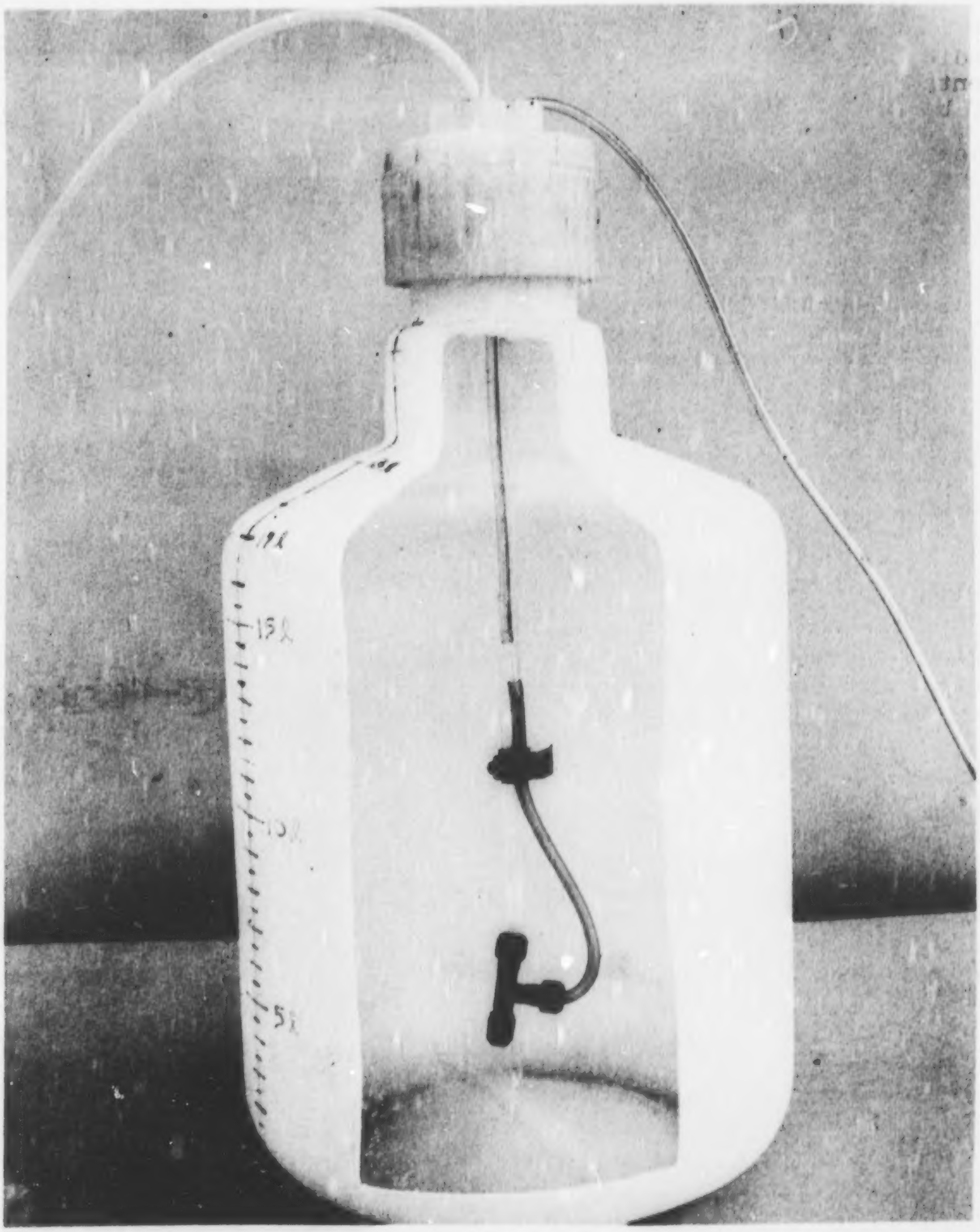

Figure 25. Air lift Clorox feeder

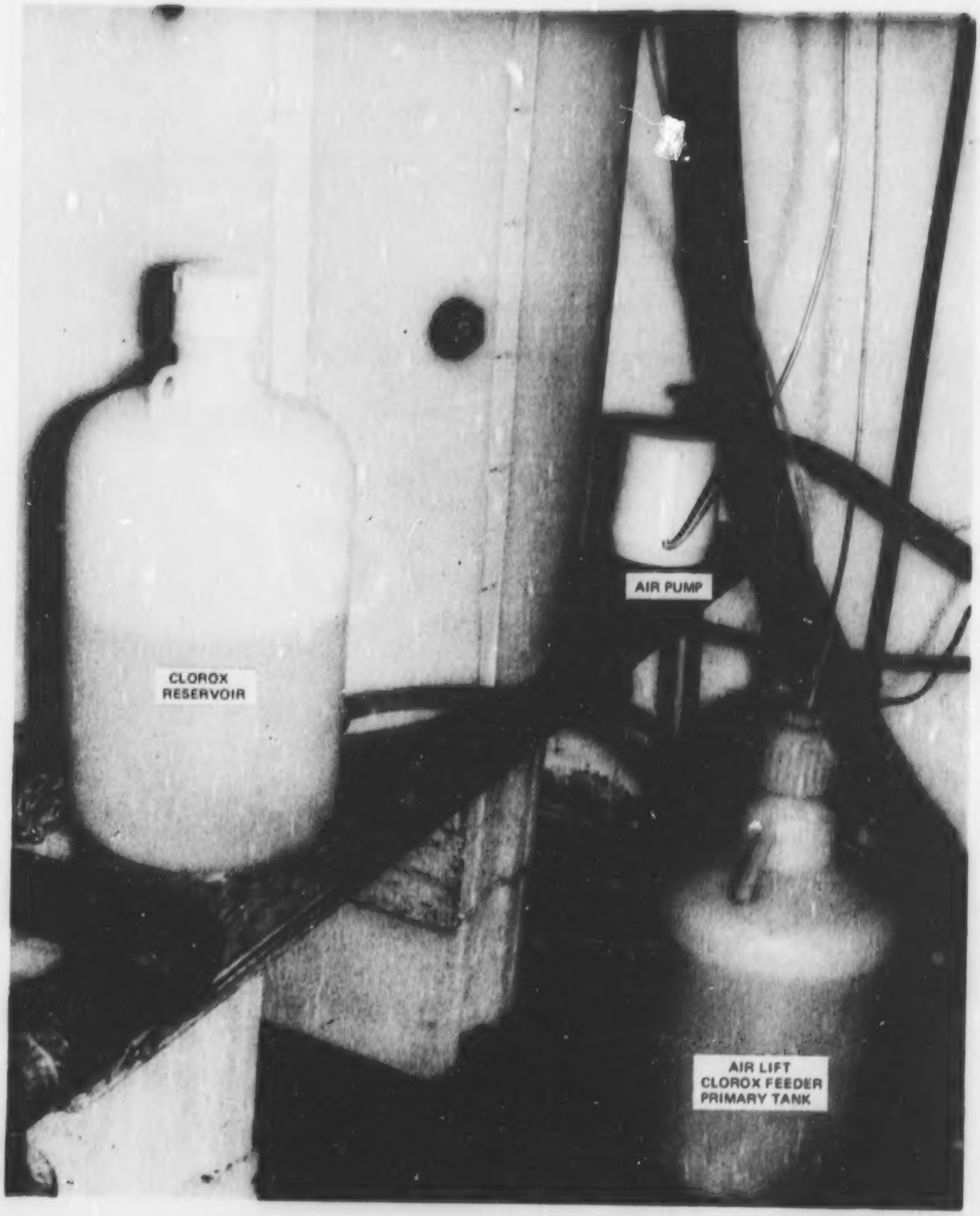
CLOROX
RESERVOIR
AIR PUMP
AIR LIFT
CLOROX FEEDER
PRIMARY TANK

Figure 26. Air lift feeder installation

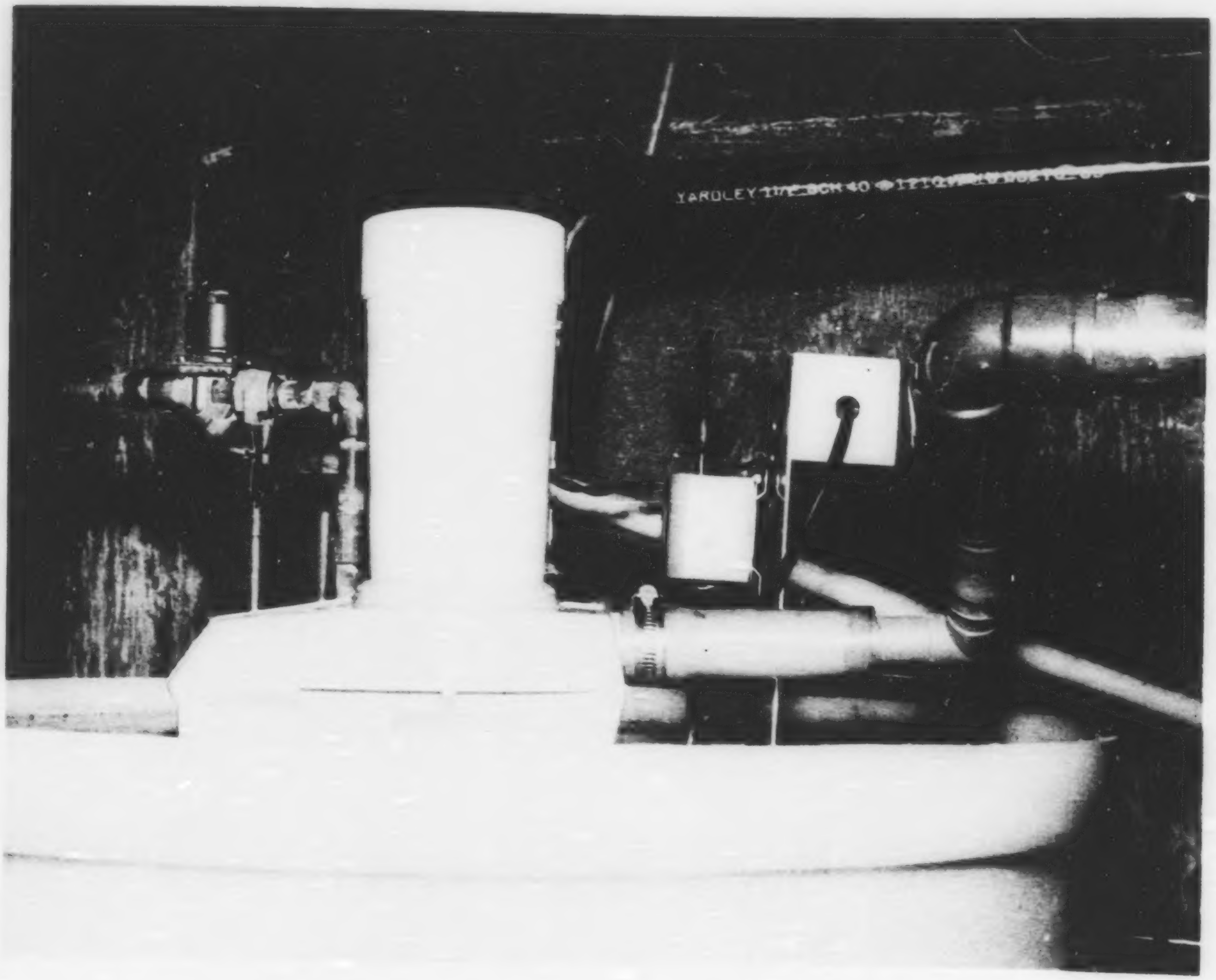
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Figure 27. Chlorine tablet feeder

Air Lift Clorox Feeder

An air lift feeder was installed and tested in home #7. A standard aquarium air pump forced air through flexible plastic tubing partially filled with the bleach solution, via a tee arrangement, and lifted droplets of bleach up into the storage tank through 0.64 cm OD (0.32 cm ID) polyethylene tubing. The chlorine dosage rate was controlled by adjusting either the feed rate or the strength of the bleach solution (0.85 - 1.7% NaOCl). The feed rate was governed by the level of bleach inside the main feeder bottle (in which the bubbler was immersed). The average feed rate was approximately 25 cc/hr, corresponding to chlorine dosage levels of from 20-25 mg/l. The bleach solution was maintained at the desired level with the aid of a feeder set-up as shown in Figure 26.

The Clorox reservoir consisted of an air tight (screw cap closure) plastic aspirator bottle, filled with bleach solution with flexible plastic tubing attached. The tubing was inserted into the bleach solution primary feed container (Figure 25) to the desired depth. As long as the end of the tubing remained immersed in the bleach solution, no transfer of bleach took place due to the vacuum which existed in the Clorox reservoir bottle. When the level of bleach in the primary container dropped so as to expose the end of the tubing, the vacuum was broken and gravity flow took place with air bubbles displacing the fluid transferred. The flow continued until the end of the tubing was no longer exposed and the vacuum re-established.

Replenishment of the diluted laundry bleach was required about every 30 days. The yearly requirement for household laundry bleach (5% hypochlorite) is estimated at 42 liters (11 gallons).

The data in Table 24 show that the air lift feeder, once properly adjusted, provided satisfactory performance in terms of odor control and germicidal action. In general, chlorine residuals of from 0.15 to 0.5 mg/l were maintained in the water closet tank throughout the test period. As expected, chlorine residuals in the storage tank showed a wider variation, ranging from 0.2 to 5 ppm. As long as measurable chlorine residuals were maintained, no unpleasant odors were detected at the water closet or storage tank location, and the coliform counts were essentially negative ($<$ 11/100 ml). Fortunately, the wash water was disinfected at pH values near neutral, which is favorable to a high level of disinfecting efficiency.

Table 24. CLOROX AIR LIFT FEEDER - PERFORMANCE DATA

Date	Average chlorine dosage level, mg/l	Chlorine[a] residual, mg/l	Odor[b]	Total Coliform count, MPN/100 ml	Remarks
11/22	0	0	TWW	160	Without disinfection
11/30	0	0	SS	1000	
12/21	0	0	TWW	140,000	
3/1	15	0	TWW	--	Feeder installed
3/6	10	0	ND	--	
3/14	50	0.5	MC	--	
3/21	20	0.3	ND	--	Incorporated "Clorox Reservoir"
3/27	27	0.2	ND	--	
3/28	27	0.15	ND	< 11	
4/13	20	0.25	ND	--	
4/17	10	0.1	ND	--	
4/19	10	0	ND	--	
4/24	28	0.25	ND	--	
4/28	40	0.5	MC	< 3	
5/3	20	0.15	ND	--	
5/11	29	0.15	ND	< 3	
5/16	10	0	ND	--	
5/22	15	0.15	ND	--	
6/5	10	0	MS	24,000	Feeder Inoperative
6/9	20	0.25	ND	--	
6/12	25	0.2	ND	--	
6/18	20	0.15	ND	< 3	
6/30	35	0.1	ND	--	

Table 24. CLOROX AIR LIFT FEEDER - PERFORMANCE DATA-(CONT'D)

Date	Average chlorine dosage level, mg/l	Chlorine residual, mg/l	Odor	Total Coliform count, MPN/100 ml	Remarks
7/6	50	0.15	ND	--	
7/12	25	0.15	ND	--	
7/17	25	0.2	ND	--	
8/1	15	0	MS	--	
8/16	55	0.5	MC	< 3	Increased Clorox concentration
9/5	60	0.5	MC	--	
9/8	26	0.15	ND	--	Readjusted concent. downward
9/15	20	0.1	ND	--	
9/22	35	0.3	ND	--	
9/28	25	0.2	ND	< 3	
10/3	25	0.15	ND	--	
10/16	50	0.25	ND	--	

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[a] Analysis performed on samples taken at water re-use location.

[b] Odor glossary:

TWW - Typical wash water
MC - Mild chlorine
MS - Mild septic
SS - Strong septic
ND - None detected (equivalent to chlorinated tap water)

The excessively high coliform count of 24,000/100 ml noted in Table 24 was due to the inadvertent disconnection of electric power to the air pump. This rendered the air lift feeder inoperative for several days. Such an incident would not occur in a permanently installed system.

HTH Chlorine Tablet Feeder

A commercially available chlorine tablet feeder was installed and tested in homes #6 and #8. The feeder was first incorporated into the diatomite filtration system of home #8, with filtered wash water continuously recirculated through the feeder. Chlorine dosage levels were controlled by (a) adjusting the immersion depth of the chlorine tablets, and (b) adjusting the rate of flow to the feeder. HTH (calcium hypochlorite) tablets were first used, but problems in controlling the dosage level were encountered due to its rapid dissolution rate and incomplete solubility At normal recirculation rates, excessive chlorination resulted. At low flow rates, the tablets exhibited a tendency to coalesce in the feeder, blocking further dissolution. The HTH tablets were subsequently replaced by completely soluble chlorinated iso-cyanurate tablets which dissolved at a much slower rate. However, the chlorinated iso-cyanurates were found to be significantly less effective than hypochlorites, per unit weight of chlorine, in maintaining odor control, and higher residuals had to be maintained (1-2 ppm). In addition, with normal recirculation rates and present feeder design, the extent of tablet immersion was critical in order to avoid under of over chlorination, making frequent adjustments necessary.

A second chlorine tablet feeder was installed in home #6. The set-up incorporated a solenoid-controlled return line to the feeder. The solenoid valve was, in turn, activated by the jet pump pressure switch, and admitted filtered, pressurized wash water to the feeder concurrently with pump operation. Hence, in this case, the chlorine feed profile coincided with the household toilet flushing pattern. Both the return flow rate and tablet immersion depth were adjusted to provide an average dosage level of 20 to 30 mg/l based on the average water closet consumption. Due to the intermittent type of operation, calcium hypochlorite tablets were able to be used successfully. Chlorine odors emanating from the dispenser were minimal. The feeder held approximately 200 HTH tablets, providing a replenishment interval of about 80 days. Approximately 3.6 Kg (8 lbs) of HTH tablets would be required on an annual basis.

Performance data for the tablet feeder installed in home #6 are shown in Table 25. During normal operation, chlorine residuals of from 0.1 to 1.0 mg/l were maintained. On one

Table 25. CHLORINE TABLET FEEDER - PERFORMANCE DATA

Date	Average chlorine dosage level, mg/l	Chlorine residual, mg/l	Odor	Total Coliform count, MPN/100 ml	Remarks
1/17	0	0	TWW	--	Without disinfection
1/26	0	0	TWW	--	
2/2	0	0	TWW	--	
2/9	20	0.1	ND	--	Installed floating basket dispenser
2/11	10	0	ND	--	
3/2	28	0.5	ND	--	
3/3	200	5	MC	--	Incorp. manual recirc.
3/15	0	0	TWW	--	Feeder not in service
3/29	25	0.15	ND	--	Re-installed dispenser
4/10	20	0.1	ND	--	
4/19	10	0	ND	--	
4/26	5	0	TWW	--	
5/26	25	0.15	ND	< 3	Installed HTH feeder
5/31	50	1.0	ND	--	
6/5	25	0.15	ND	--	
6/7	25	0.15	ND	--	
6/9	200	5.0	SC	--	Pump running excessively
6/13	25	0.3	ND	< 3	
7/13	25	0.1	ND	--	

Table 25. CHLORINE TABLET FEEDER - PERFORMANCE DATA (CONT'D)

Date	Average chlorine dosage level, mg/l	Chlorine residual, mg/l	Odor	Total Coliform count, MPN/100 ml	Remarks
8/1	20	0.3	ND	--	Lawn sprinkling only
10/5	10	0.2	ND	--	Diatomite filter operational
10/12	15	0.1	ND	--	
10/18	20	0.1	ND	--	
11/19	25	0.15	ND	--	

occasion, over-chlorination was produced when the jet pump remained running for an excessively long period of time due to clogging of the Fram filter. Such an occurrence can be prevented by the incorporation of a pump vacuum switch set for 65 cm Hg. The intermittent chlorination provided by this tablet feeder proved to be as successful as the continuous (Clorox) feeder in controlling odors and bacterial growth.

Fluid Transfer and Pressurization

A pump is required to pressurize the filtered wash water and make it available for toilet flushing and/or lawn irrigation. A pressure range of 100 to 200 cm Hg is generally considered adequate for these purposes. An additional pressure differential is required (0-50 cm Hg) to draw the water through the filtration system. In order to meet these pressure requirements at flow-rates ranging from 19 to 38 lpm, a 1/3 HP shallow well jet pump was selected (Flint and Walling Model C833). The pump was mounted on either a 45 or 115 liter pressure tank, and was provided with an air volume control to maintain sufficient air space inside the tank, as shown in Figure

28. Operation of the pump was controlled by a pressure switch set to maintain the pressure between 100 and 200 cm Hg. The pump motor was rated at 115V/5.6 amps with a starting surge of 8.6 amps.

The 1/3 HP jet pump provided reliable and satisfactory performance in terms of transferring wash water through the filter and subsequent pressurization. The pump was capable of handling filter pressure drops (vacuum) up to 65 cm Hg while pressurizing the wash water to 210 to 260 cm Hg during water closet reuse. During normal operation, flow rates of from 20 to 40 lpm were provided. The pump running time was very short, averaging about one-half minute per water closet flush. The air volume control worked satisfactorily in two of the three pumps installed. Recurrent flooding of the pump installed in home #7 was traced to defective air volume control fittings. Subsequent installation of a Schrader air valve allowed for satisfactory pump operation. In home #6, a leak developed at the pump inlet connection due to improper installation of a threaded PVC adapter. Subsequent replacement with cast iron fittings back to the check valve eliminated the leak problem.

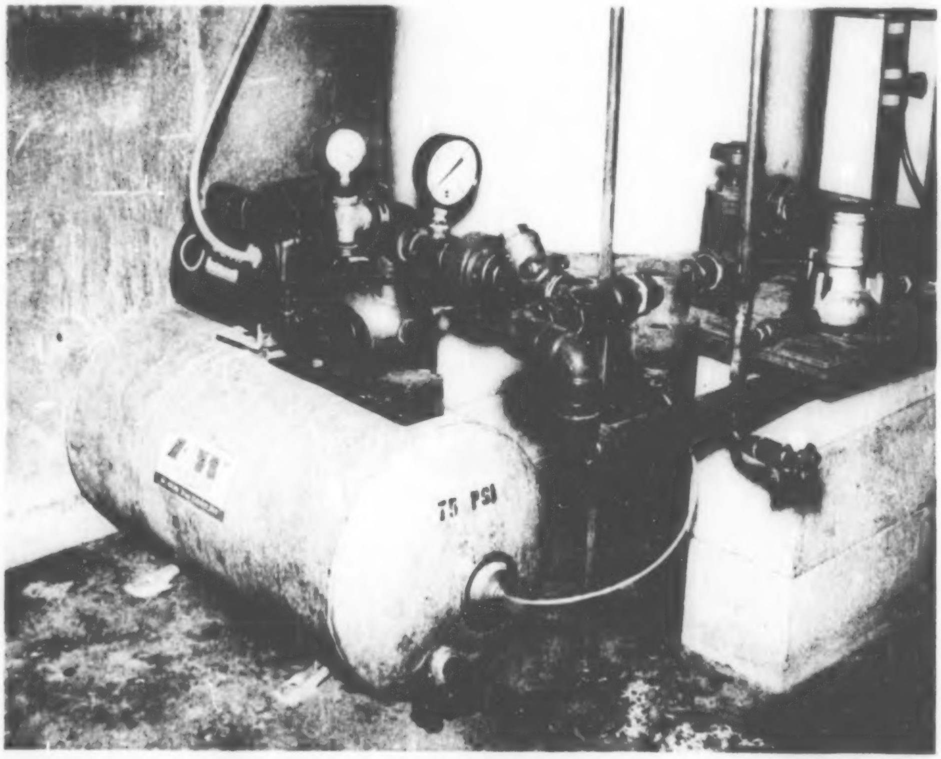

Figure 28. Pressurization system

SECTION VII

HOMEOWNER ACCEPTANCE

GENERAL

The continued use and success of the various water saving devices and systems installed in the eight test homes ultimately depends upon acceptance by the homeowner. The homeowner's decision may be based primarily on socially conditioned attitudes, or on functional criteria such as performance, cost, and maintenance. In order to determine and evaluate the reactions of the people who participated in the demonstration program, a formal questionnaire was prepared and distributed to all adult occupants. Despite the relatively small sample size (a total of 16 respondents), the survey did provide a clear indication of the relative acceptability of each of the water saving devices tested.

A sample of the questionnaire with the tabulated results of the survey is included in the Appendix. A summary of the survey results in terms of user acceptance is presented in Table 26. The responses were generally favorable toward the use of all of the devices and systems tested.

It should be noted that all of the volunteer homeowners were General Dynamics employees. The selection of General Dynamics employees was made in order to (a) help assure continuance in the program throughout its entirety, (b) maximize exchange of information, (c) facilitate monitoring and maintenance of experimental devices and systems, and (d) achieve better homeowner participation.

Table 26. SUMMARY OF QUESTIONNAIRE RESULTS

Device or system tested	Number of respondents	Percent of responses which indicated user acceptance
Flow limiting shower heads	16	88
Shallow trap water closet	12	83
Dual-flush devices	6	100
Toilet flushing reuse	6	67
Lawn sprinkling reuse	4	50

Although the possibility of biased attitudes affecting the results of the survey cannot be absolutely refuted, it is believed that the respondents answered the questionnaire honestly and objectively, with any bias due primarily to pre-conditioned attitudes unrelated to their association with the contractor. The fact that the participants were selected on a voluntary basis does suggest a certain level of identification with the objectives of the program and perhaps a greater predisposition towards acceptance of a particular device than if chosen at random.

FLOW LIMITING SHOWER HEADS

A total of eleven flow limiting shower heads were installed in the eight test homes. Eight shower heads (5 homes) were of the type which limited the flow to 13.3 lpm (3.5 gpm). Unanimous acceptance of this particular type was indicated in terms of providing an adequate water supply, spray pattern, and overall performance. The remaining three shower heads (3 homes) incorporated a 9.5 lpm (2.5 gpm) flow limiting orifice. Two-thirds of the respondents using this type shower head found the device acceptable.

SHALLOW TRAP TOILET

Shallow trap water closets were installed in six of the eight test homes. Eighty-three percent of the respondents indicated that they found the toilet performance acceptable and would recommend it to others. The remaining 17% found that they had to double flush the water closet approximately 10% of the time, and apparently judged this to be unsatisfactory performance. A small increase in the water closet flush volume, by either raising the water level or increasing the fill rate, may have eliminated the problem in one of the homes. All of the respondents stated that they were satisfied with the appearance of the toilet and indicated maintenance requirements were minimum.

DUAL-FLUSH DEVICES

A total of eight dual-flush devices were tested in three homes. All six respondents indicated that each device was easily installed and operated. All of the people surveyed indicated that the devices provided an adequate flush for solids and liquids. Two-thirds of the respondents found the reduced flush adequate for solids as well as liquids. Use of the reduced or "light" flush averaged approximately 50% of all flushes. The necessity of having to hold the flush handle while the water closet tank was being emptied in order to effect a full flush with the Sink-bob or Saveit device apparently did not discourage any of the users. All of the adult participants considered the retail price of each device to be within reasonable limits. Costs are given in Table 27 in the Cost Analysis Section.

WASH WATER RECYCLE SYSTEM

Toilet Flushing

Wash water recycle systems were installed in three homes in Southeastern Connecticut. All six adult respondents indicated that the system was manageable, simple to use, provided an adequate water supply for toilet flushing, and performed satisfactorily. Fifty percent considered the maintenance requirements minimum. All of the occupants indicated that there were additional cleaning requirements for the toilet bowl with this system due to temporary discoloration or staining. One of the six adult participants found the reuse of treated wash water for toilet flushing objectionable and disapproved of the appearance of the water. One-third of the participants expressed concern about odor control and for a possible health hazard. None of the respondents indicated any problems due to excessive foaming. Two-thirds of the adult users indicated they would recommend the use of this system to others.

By way of comparison, a recent public opinion survey by Bruvold and Ward[10] in the State of California showed only 5% of the sampled population to be opposed to the reuse of reclaimed water for toilet flushing.

Lawn Sprinkling

All four adult participants involved in the reuse of wash water for lawn watering did not notice any obvious adverse nor beneficial effects as compared with conventional lawn watering. No effect on sprinkler system operation was noted. Both households expressed concern for a possible health hazard. One-half of the participants were willing to continue using this system, as well as recommend it to others.

GENERAL

Fifty percent of all respondents indicated that they realized a cost savings during the test program as a result of a decreased water or electric bill. Seventy-five percent of the households served by a septic system experienced a noticeable decrease in service requirements for these facilities during the test period. Based on the commercial availability of recycle systems, 44% of all respondents expressed an interest in toilet flushing reuse, and 31% in lawn watering reuse. The prices they would be willing to spend on a recycle system ranged from $200 to $500.

SECTION VIII

COST ANALYSIS

INTRODUCTION

Most people are interested in water pollution abatement and are willing to encourage the spending of government money for various pollution abatement programs. However, they are understandably less willing to spend their own money for private pollution control measures when their neighbors are not also compelled to do so, except in those circumstances where private water supply and/or waste treatment facilities are inadequate. There is also a general lack of interest in devices to reduce water usage in this country as the result of generally plentiful water supplies, rate schedules which tend to penalize water conservation, and indirect methods for the recovery of capital costs associated with the construction of pollution control facilities. Household flow reduction is not likely to become widespread unless water users are thoroughly convinced, not only of the desirability of using water saving devices, but also convinced that use of these devices would not result in a cost penalty, and could even result in a cost savings.

COST SUMMARY

Bathroom Water Saving Devices

The installed cost for each of the water saving devices tested is shown in Table 27. The material costs are based on the retail prices at which these devices are currently available to the homeowner. It is assumed that the toilet inserts (reduced flush devices) and flow limiting shower heads will be installed by the homeowner. The total annual cost was based on amortization* of the installed cost over the expected life of the device. The cost of toilet inserts, such as the Econo-Flush, Sink-Bob, and Saveit, are expected to decrease as the market for these kinds of devices expands.

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*No interest was charged for determining costs in this study, the assumption being made that interest would not be a factor with the relatively small costs involved.

Table 27. COST SUMMARY - BATHROOM WATER SAVING DEVICES

Water saving device	Material Cost-$	Labor Cost-$	Installed Cost-$	Operating Cost-$	Expected Life,yrs.	Total Annual Cost-$/yr.
Shallow-trap flush toilet	60	15	75	0	20	3.75
Dual flush devices						
Sink-Bob	4	0	4	0	10	0.40
Econo-Flush	14	0	14	0	10	1.40
Saveit	6	0	6	0	10	0.60
Flow limiting shower heads						
13.3 lpm	6	0	6	0	15	0.40
9.5 lpm	8	0	8	0	15	0.53

Wash Water Recycle Systems

The cost of the various components associated with the installation and operation of the two different types of recycle systems are shown in Table 28. For the prototype recycle systems, the installed cost of the system with the diatomite filter is seen to be $100 higher than the cartridge filter system ($640 vs. $540), the difference attributable to higher costs for filtration, piping, and installation. Storage system costs were based on the use of a 380 liter polyethylene tank, and included provisions for a low-level control system and tank elevation, if required. Approximately one-half of the labor costs shown are due to connection to the house plumbing and will vary somewhat from home to home.

Tabulations of the operating costs associated with filtration, pressurization, and disinfection are shown for the prototype systems. The rather modest filter media costs for the diatomite filter are based on the use of 3.7 kg of diatomite per year (at $0.40/kg), and replacement of the filter system every five years. The relatively high operating costs for the cartridge (Fram) filter reflect an average cartridge replacement interval of approximately two months, and a cartridge replacement cost of $5.85. Filter media costs for the Cuno filter (10 micron depth cartridges) averaged $40/yr. Approximately 90% of the electric power

Table 28. COST SUMMARY - WASH WATER RECYCLE SYSTEMS

	Prototype Recycle Systems		Projection for mass produced recycle system
	Diatomite filter	Cartridge filter[a]	(Diatomite filter)
A. Initial cost			
Storage sys.	$175	$175	$70
Filter sys.	135	60	100
Pressurization sys.	115	115	85
Disinfectant feeder	20	20	20
Valves, pipe, fittings	95	80	75
Total Mat'l Cost	540	450	350
Labor Cost	100	90	50
Total Installed Cost	$640	$540	$400
B. Annual operating cost			
Filter media	$3.50	$38.80	$3.50
Electric power	12.00	1.20	7.00
Disinfectant	5.50	5.50	5.50
	$21.00	$45.50	$16.00
C. Total annual cost			
Expected life years	15	15	15
Total cost per yr	$63.50	$81.50	$43.00

[a] Fram filter selected for cost analysis

requirements for the diatomite filtration system arise from the need for recirculation, with the remaining portion due to pressurization for toilet flushing. Calculation of the power requirements was based on a 16-hour-on/8-hour-off cycle for the recirculation pump, and a unit electricity cost of $0.02 per Kwh. Chlorination costs for both the diatomite and cartridge filter systems were based on maintaining an average dosage level of 25 mg/l using chlorine tablets (CaOCl) at a rate of 3.6 kg per year. Other methods of disinfection were about equivalent in cost. The total operating cost for the recycle system, incorporating a cartridge filter, is seen to be more than twice as high as that for the diatomite filter system due to the difference in filter operating costs of $24.50 per year.

The total annual costs were determined by amortizing the initial costs over an expected life of 15 years and adding the respective operating costs. The total cost for the cartridge type recycle system is almost 30% higher than the diatomite system, as the relatively high filter media cost for the former system overshadows its lower initial cost.

Projected costs for a mass produced, cost optimized version of the diatomite type recycle system are also included in Table 28. A substantial cost reduction is projected for the storage system based on the use of two modified 208 liter (55 gallon) drums with polyethylene liners. The use of preassembled subsystems should decrease installation costs by about one-half. Due to the short pump running time required for toilet pressurization, a less expensive jet pump should be satisfactory. The 42% reduction in electric power requirements shown in Table 28 reflects an anticipated corresponding reduction in filter recirculation requirements which should be attainable without compromising effluent clarity at the point of reuse. This can be implemented by the inclusion of an additional, limited range pressure switch mounted on the pressure side of the jet pump which would activate the recirculation pump. With this set-up the filter cake would be applied to the filter system, and filtered water would be circulating through the lines prior to jet pump activation. The total annual cost for the mass produced recycle system is estimated at $43 per year, corresponding to a projected cost reduction of 32%.

ECONOMIC FEASIBILITY

An assessment of the economic feasibility of the various water savings devices tested during this program was made in terms of their potential for cost savings through flow reduction. In Table 29, the cost per unit volume of flow reduction effected by each device or system is presented

Table 29. COST COMPARISON

Flow reduction device		Cost per unit vol. of flow reduction $/1000 liters	Typical water rates $/1000 liters	Typical sewer rates $/1000 liters	Septic tank system - poor soil $/1000 liters	Net Savings $/year
Shallow trap water closet		0.15	0.16 - 0.42	0 - 0.13	---	$.25 to 9.80
Dual flush devices	Sinkbob	0.02	0.16 - 0.42	0 - 0.13	---	$4.10 to 15.60
	Econoflush	0.07	0.16 - 0.42	0 - 0.13	---	$1.72 to 9.20
	Saveit	0.04	0.16 - 0.42	0 - 0.13	---	$2.40 to 10.20
Flow limiting shower heads	13.3 lpm	0.08	0.16 - 0.42	0 - 0.13	---	$1.10 to 5.32
	9.5 lpm	0.22	0.16 - 0.42	0 - 0.13	---	$.52 to 3.53
Wash water recycle system	Prototype	0.57	0.16 - 0.42	0 - 0.13	0.40	$-45.70 to -2.30[a] --------- $-1.30 to 27.60[b]
	Mass-produced	0.39	0.16 - 0.42	0 - 0.13	0.40	$-25.20 to 18.20[a] --------- $19.20 to 48.10[b]

[a] Net savings per year based on water and sewer rates

[b] Net savings per year based on water rate and septic system cost

and compared with typical water and sewerage rates. For the recycle systems, the basis of comparison was expanded to include septic tanks with poor soil absorption systems.

In most instances, water supply facilities are operated as a utility, and water use rates are adjusted to recover the total cost incurred (operating cost plus level debt service) plus some nominal profit. Domestic water rates throughout the State of Connecticut range from $0.16 to $0.42 per 1000 liters. Water rates in the primary test area (Southeastern Connecticut) average $0.32 per 1000 liters. Waste treatment facilities are normally operated by the municipal government, and sewerage use charges are much less than the actual cost of wastewater collection and treatment. Usually, homeowners are billed directly only for operational costs of sewerage services. Other costs, such as planning, engineering, and construction of waste treatment and collection facilities, are covered by initial assessment fees, bond issues, and property taxes. Because of encouragement by recent federal guidelines for supplemental funding of new waste facilities, there is a trend towards consolidation of water and waste treatment management and towards the distribution of operating costs on the basis of water usage rather than fixed service charges. Typical sewerage use rates in the Connecticut area range from zero for increments in use (fixed service charges)to $0.13/1000 liters. Treatment costs for septic systems with poor soils are based on data from References 11 and 12, (not updated, therefore a conservative basis).

When compared with typical water and sewer use rates, all of the bathroom flow reduction devices listed were shown to be economically acceptable in terms of cost savings. In general, the dual flush devices show the greatest potential for cost savings, even when considered for those communities in which water rates are low to average, and sewer rates are not based on water consumption. The flow limiting shower heads, despite their low cost, proved to be of less economic value than anticipated largely because of the rather limited water savings obtained with these devices. At least one-half of the cost savings shown for shower heads are attributable to a reduction in hot water heating requirements. The shallow trap toilet is definitely warranted in terms of cost savings for new installations or necessary replacements, since the material and installation costs for the standard and water saving toilets are approximately the same. Because of its relatively high cost, however, the shallow trap toilet appears to be of limited economic value for replacement of workable toilets.

The cost analysis of the system to reuse waste wash water for toilet flushing and/or lawn sprinkling indicates that household recycle units become economically attractive when septic tank systems with poor soils or other inadequacies are encountered. It should be borne in mind that the water savings indicated ($19 to $48/yr.) apply only to situations where existing septic systems are inadequate, or where new septic tank installations are being planned and incorporation of the recycle system will permit a less expensive septic system. Comparison of the projected cost of the mass produced version with typical water and sewer rates indicates that the system can also effect marginal cost savings in high water rate areas. However, from a strictly economic point of view, the potential cost savings attainable in such circumstances ($18.20/yr.) is less than one would obtain by investing an amount equal to the system initial cost at 5% interest.

Steadily dwindling reserves of fresh water for domestic consumption in many areas of the country and the continuing emphasis on advanced waste treatment will undoubtedly encourage future reuse of waste water at both the household and community levels through higher water and waste treatment rates. Another method of encouraging water conservation and reuse would be to make the true cost of waste water collection and treatment more visible to the individual user. This can be accomplished if the municipality is able to recover some or all of the associated capital costs by direct charges to the consumer on the basis of water usage. Federal guidelines on user charges show a trend in this direction.

SECTION IX

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SECTION X

APPENDIX

HOMEOWNER'S QUESTIONNAIRE SUMMARY

	NUMBER OF RESPONSES	
	Yes	**No**
A. FLOW LIMITING SHOWER HEAD DEVICES		
1. Was the device attractive in appearance?	16	0
2. Did the fixture provide an adequate supply of shower water for your purposes?	14	2*
3. Did the fixture provide an excessive supply of water for your purposes?	1	15
4. Did the device perform satisfactorily?	16	0
5. Was the maintenance considered minimum?	16	0
6. Did you require more time to shower with this head than with your previous shower head?	2*	14
7. Would you recommend the use of this device to others?	14	2*
8. Did the device provide an acceptable spray pattern?	14	2
9. Please indicate roughly what percentage of your total bathing was accomplished by showering?	30-100%	

*9.6 lpm shower head

B. SHALLOW-TRAP TOILET		
1. Was the toilet attractive and acceptable from a decorative viewpoint?	12	0
2. Did the toilet provide an adequate flush for everyday toilet use?	10	2

B. SHALLOW-TRAP TOILET (Cont'd)

		NUMBER OF RESPONSES	
		Yes	No
3.	(a) Was a second flush ever required?	9	3
	(b) If yes, approximately how often?	Aver. 10%	
4.	Did the device perform satisfactorily?	10	2
5.	Was the maintenance required minimum?	12	0
6.	Would you recommend the shallow-trap toilet to others?	10	2

C. DUAL-FLUSH DEVICE

		Yes	No
1.	Was this device easily operated?	6	0
2.	Did this device provide for an adequate flush for the waste solids?	6	0
3.	Was the reduced flush adequate for liquid wastes?	6	0
4.	Did the device provide an excessive supply of water for flushing purposes?	0	6
5.	Approximately how much of the time was the reduced flush used?	50%	
6.	Was use of the full flush inconvenient?	0	6
7.	With the toilet device installed, have you found it necessary to clean the toilet bowl more frequently?	0	6
8.	Was the device easily installed?	6	0
9.	Did the device function satisfactorily?	6	0
10.	Was the maintenance required minimum?	6	0
11.	Would you recommend this toilet device to others?	6	0
12.	Do you feel the retail price is too high?	0	6

Econo-Flush:	$13.95
Sink-Bob:	$ 3.00 - $4.00
Saveit:	$ 6.99

	NUMBER OF RESPONSES	
	Yes	No
D. RECYCLED WATER SYSTEM FOR TOILET FLUSHING		
1. Did you find the recycled water system complex to use?	0	6
2. Did you find the system unmanageable?	0	6
3. Did the system provide an adequate water supply for flushing purposes?	6	0
4. Did the system perform satisfactorily?	6	0
5. Was the maintenance required minimum?	3	3
6. Did the system require a minimum of surveillance?	4	2
7. Did you find the reuse of treated wash water for toilet flushing objectionable?	1	5
8. Were there additional cleaning requirements for the toilet bowl with this system?	6	0
9. Were there any problems because of:		
a) odors generated?	2	4
b) appearance or color of the water?	1	5
c) excessive discoloration or staining of the toilet trap?	6	0
d) excessive foaming?	0	6
e) the requirement and use of disinfectants?	3	3
f) a concern for a possible health hazard?	2	4
g) the design of the system?	1	5
10. Would you recommend this system to others?	4	2
E. RECYCLED WATER USED FOR LAWN OR GARDEN WATERING		
1. Did the use of treated laundry/bath water for lawn or garden use have any obvious adverse effect on your lawn or soil?	0	4
2. Did it have any beneficial effect over conventional lawn watering?	0	4

E. RECYCLED WATER USED FOR LAWN OR GARDEN WATERING (Cont'd)

	NUMBER OF RESPONSES	
	Yes	No
3. Would you recommend use of this system to others?	2	2*
4. Did you feel a concern for any possible health hazard?	2	0
5. Did the use of the system have an adverse effect on the operation of the sprinkler system?	0	2

*Homeowner #7 felt that manually operated lawn watering reuse was impractical for his situation. He did indicate approval of an automatically operated sprinkler set-up.

F. GENERAL

1. Did you realize a cost savings during the test program through the use of water saving devices or a recycling system by:

	Yes	No	No way to evaluate
a) decreased water bill?	6	2	8
b) decreased electric bill?	2	5	9
c) decreased fuel bill?	0	2	14
2. If the home was served by a septic tank or leach field, were there any noticeable changes in service requirements for these facilities during the study?	6	2	---

If yes, explain: See Section VIII for explanations.

3. Do you plan to include in your home any of the following devices when this test is completed?

	Yes	No
a) restrictive flow shower-head device?	13	3
b) toilet flush water saving device?	5	1
c) shallow-trap toilet?	10	2

F. GENERAL (Cont'd)

	NUMBER OF RESPONSES	
	Yes	No
4. If recycle systems were commercially available, would you:		
a) reuse laundry/bath water for toilet flushing?	4	2
b) reuse laundry/bath water for lawn or garden watering?	2	4
5. If answers to 4(a) and/or 4(b) were yes, how much would you be willing to spend? No more than:		
$200 1 , $300 2 , $400 2 , $500 2 , $600 0		
6. Would you recommend homeowner's participation in other test programs such as this?	14	2
7. Other comments and suggestions concerning this test program would be appreciated.		

G. IDENTIFICATION

Name________________________

Age__________ Sex__________

Relation to homeowner________